# A DESCRIPTION *of an* AIR-PUMP *of a* NEW CONSTRUCTION, *with an* ACCOUNT *of its* PERFORMANCE, *and of ſome* EXPERIMENTS *and* OBSERVATIONS *tending to aſcertain the* CIRCUMSTANCES *on which the* PERFECTION *of that* MACHINE *depends, and to render its* THEORY *more compleat.* *By the Rev.* JAMES LITTLE *of Lacken in the County of Mayo.*

Read Dec. 17th 1796.

THE many diſcoveries which have done honour to the exertions of the electricians and chemiſts, even ſince the middle of this century, encourage us to hope that their labours will not terminate 'till they become the means of affording to poſterity a more extenſive knowledge of the latent principles and powers of nature, and conſequently a more devout conviction of the wiſdom of its great Creator, than there was any proſpect of in the preceding age. Such knowledge of the works of God, ſought out of all them that have pleaſure therein, and affording unexpected advantages to human life, is the reſult of experimental enquiry; and experiments cannot be made without proper inſtruments

ments and machines. Of theſe, none has opened a wider field of enquiry in natural philoſophy than the air-pump; and I am inclined to think, that this inſtrument has not yet afforded all the ſervices of which it is capable, when I conſider that air is ſo large a component part of moſt bodies, that ſince many kinds of air are compounded of other aeriform fluids, and aſſume different qualities according to the varieties of their combination, theſe component fluids would in many experiments be with moſt advantage united in vacuo; and alſo that ſome electrical experiments not only require a vacuum, but alſo one of the moſt perfect kind.

WITH a view to this latter circumſtance ſolely, ſo long ago as the year 1776, I ſet about contriving an air-pump which ſhould be ſimple in its conſtruction and yet exhauſt more perfectly than thoſe of the common form; and in 1778 I made one (the barrel of which was of pewter metal) on the principle, which, I was ſatisfied from the following theory, was the moſt eſſential, of leaving as little air as poſſible under the piſton when put down to the bottom of the barrel; and the performance of this machine was ſo excellent as to induce me to fabricate a larger and more perfect one of the ſame conſtruction, and made in braſs-metal, which I had executed (in the country) in the year 1785; but not finding it to perform as well as I had expected, I deviſed an alteration and improvement in it, which I had almoſt finiſhed the workmanſhip of in 1788, being that

which

which is here defcribed; and from that time 'till the laft fummer (1785) it lay by me neglected, bad health, &c. diverting my attention from it; for the whole of it, except the forging the iron-work, was made by myfelf without affiftance. At length, being loth to lofe my labour, I put the laft hand to it. Before it was finifhed, I was acquainted with the conftruction of Mr. Smeaton's air-pump, with its improvements, but had not heard of Mr. Cuthbertfon's; which, as well as Mr. Smeaton's, I find is conceived on the fame principle with mine, yet the application of that principle in the machine here defcribed, being exhibited in a much more fimple conftruction, it will I am perfuaded be found to perform better and with more certainty than the former, on which perfuafion only I am induced to publifh it. The reader will eafily underftand what is hereafter faid of its theory, after he has confidered its conftruction.

THE principal parts of it are one barrel and pifton, one ftop-cock, one valve, and two pipes of communication.

N. B. THE pump here defcribed is a portable one, and fo contrived as to be confined in a very fmall fpace; but it may be made of a different form, and with two barrels, though not conveniently.

FIG. 1. is a perfpective view of the whole machine as it lies before the operator. Fig. 2. is a back-view of the fame.

The barrel A A, (fig. 1.) is almoſt fifteen inches long, and internally in diameter juſt two inches; it is moſt perfectly cylindrical, and poliſhed like a looking-glaſs within. The piſton (fig. 3.) is ſolid, without any perforation; it conſiſts of circular plates of leather preſſed together between the round plate *a*, (in the ſocket of which *b*, the piſton rod was inſerted and faſtened by a croſs ſcrew, before the leathers were put on) and the two upper plates *c* and *d*; of which the outer one *d*, being ſcrewed upon a ſcrew formed on the outſide of the ſocket, preſſes down the under plate, and this the leathers, which latter are not repreſented in the figure. The upper plate, when ſcrewed on, lies even with the upper part of the ſocket, that, when the piſton is raiſed to the top, it may touch the plate covering the upper part of the barrel, leaving no air above the piſton. Theſe two plates of the piſton, eſpecially the lower one, are made ſo large as juſt to move in the barrel without touching it, and care was taken that when the piſton is put down, it ſhould be every where in contact with the plate at the bottom of the barrel, this plate being turned in the lathe upon the piſton rod which fitted its ſocket exactly, ſo that not the leaſt ſpace might be left for lodgment of air under the piſton. The leathers are of the beſt buck-ſkin, dreſſed in the uſual manner, firm in its texture, but not harſh; and being well dried, were ſoaked in a mixture of three parts ſuet melted with one part oil, before they were put together: they

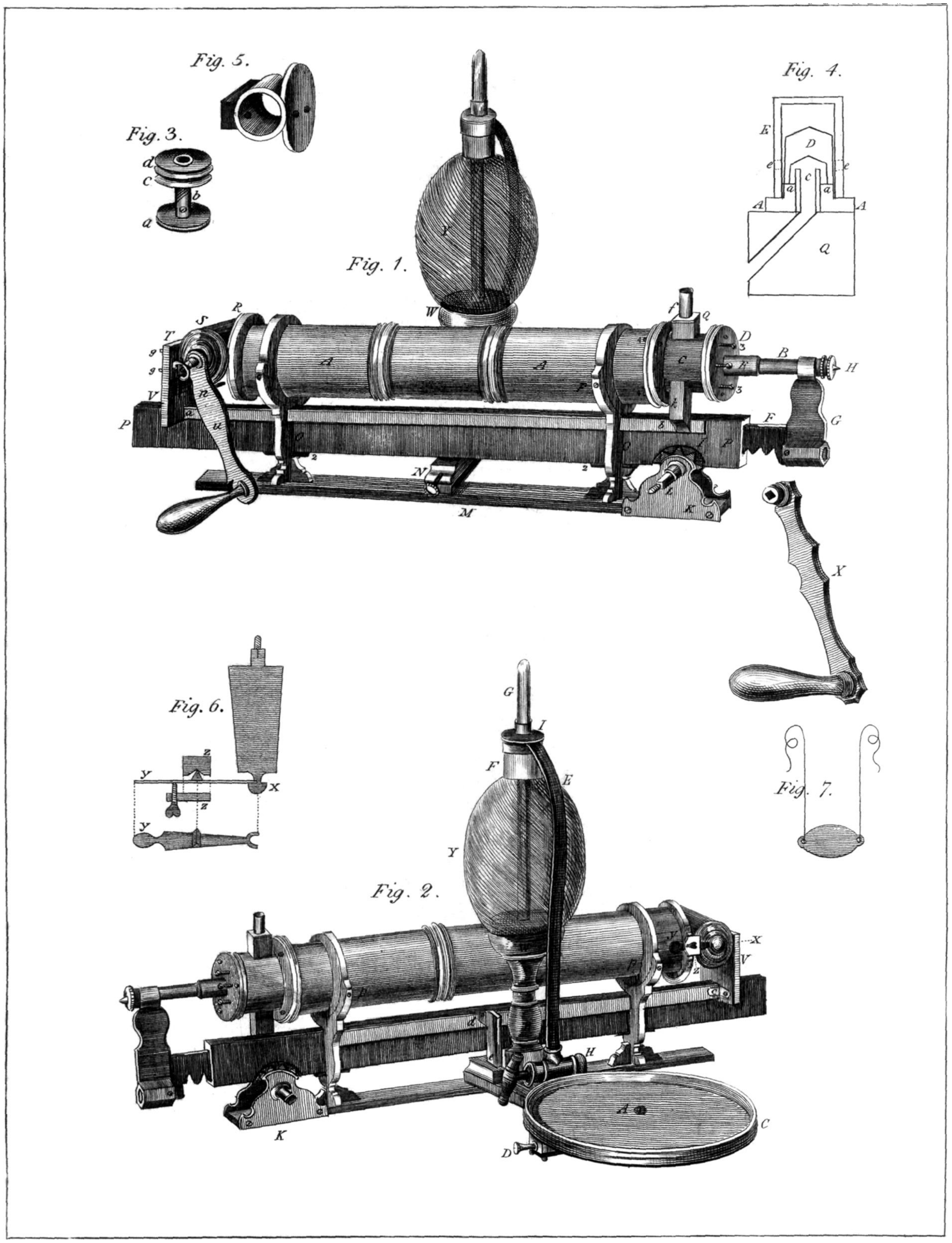
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.

they were then, when cold, turned in a lathe on the piſton, with a very ſharp tool *.

THE iron rod of the piſton is $\frac{45}{100}$ths of an inch in diameter, exactly cylindrical, and very ſmoothly poliſhed; it moves through a collar of leathers (the ſame kind as thoſe of the piſton) encloſed in the braſs box C, the lower plate of which is fixed on the top of the barrel by the four ſcrews 4, 4, paſſed through the broad prominent rim of it; and the plate was ſo well adapted to the top of the barrel, by grinding it on it with a circular motion, as to require only the interpoſition of a little ſtiff ointment to make the joining air-faſt. A cover is, in the ſame manner, adapted by three ſcrews to the projecting rim of the box containing the collar of leathers, in the middle of which cover is fixed the ſocket or collar E, above an inch long, through which the piſton rod moves. As it is altogether neceſſary that this rod ſhould move moſt

 exactly

* If tanned leather were uſed for the piſton, &c. it might be ſoaked in oil alone; but beſides that it is apt to grow too hard by compreſſion, and alſo to corrode the braſs of the barrel more from the acid imparted by the bark with which it is tanned, it alſo emits a greater quantity of elaſtic fluid in vacuo than leather which is not tanned. On theſe accounts I have uſed buck-ſkin leather for the piſton, but the texture of this being very looſe, oil only would not fill its pores ſo as to make the piſton air-tight, even when the leathers were cloſely preſſed; and it was neceſſary to fill its grain with the above ſtiffer compoſition. Yet this leather will alſo generate air, and is harder to be made air-faſt; it alſo moves ſo ſtiffly in the barrel that perhaps good ſhoe-leather is preferable to it.

exactly in the middle or axis of the barrel, care was taken that the position of the box, and of the socket annexed to it, should be secured, by having a prominent part of the plate of the box of leathers inserted into the pump barrel, and a like projecting part of the lid of the box inserted into the box itself; also that the piston rod should most exactly fill the socket in the lid. Over the collar of leathers, within the box, lies a tinned brass plate, which is pressed down upon them by the ends of three screws 3, 3, screwed through the lid of the box.

THE piston is moved up and down by the toothed flat bar or rack F, whose end is furnished with an arm G, (to be taken off occasionally) which arm is secured against a shoulder formed on the end of the piston rod, by a nut H screwed on the rod; the rack is moved by a small steel wheel L, one inch and $\frac{7}{10}$ in diameter, having twelve teeth, and which is turned by the handle X fixed on its axis L. This wheel is sustained by the cheeks K, K, fig. 1. & 2. furnished with projecting sockets, through which its axis passes. These cheeks are screwed to the iron bar M, which is a part of the frame supporting the whole machine; by this bar it is fastened by clamps to whatever table it is placed on From the middle of the bar, and at right angles with it, extends horizontally an arm N, (rivetted and brazed upon the bar) the under

under ſurface of the arm being on a level with the upper one of the bar; this arm ſupports the gage glaſs Y, and terminates in a croſs piece (making together the form of the letter T) to which piece and to the arm, the receiver-plate is ſcrewed by ſcrews underneath, inſerted into its thick margin.

THE bar M ſupports the upright pieces or pillars o, o, terminating in the ſemicircular arms p, p, on which the barrel is faſtened by four ſcrews at p, p, ſcrewed a little way into its projecting rings. Theſe pillars are made of iron, and very ſtrong, being half an inch in thickneſs; they are alſo moſt firmly fixed, and ſhould be brazed in the bar which ſupports them; this being neceſſary, as all the force of the handle of the wheel, by which the rack is worked, bears againſt theſe pillars; and, if they were to be ſhaken, the cement by which the receiver pipe is connected with the pump would be broken, which cannot otherwiſe happen. The pillars ſupport alſo the iron caſe or ſheath P P, extended underneath the pump barrel, within which caſe ſlides the toothed bar or rack F, moved by the wheel, and this rack (with its caſe) is fixed exactly parallel to the axis of the cylinder, that it may draw out the piſton rod preciſely in that direction in which itſelf moves: the bar is $\frac{3}{10}$ of an inch in thickneſs, but is an inch in breadth from the bottom of its teeth to the back of it. It is made thus ſtrong that the end of it may not be ſtrained upward

upward from the proper direction, when it is urged forward by the wheel, and yet checked by the piston rod after the piston is raised to the top of the barrel. To confine the rack in the true line of its motion, it is made perfectly straight and of the same dimensions in its whole length, and its case the same, so as to fit each other most exactly, that it may be kept in its due position when the greatest part of it is drawn out of the case; for which purpose also it is made, (as likewise the case) so much longer at either end than the part necessary to be toothed, as to permit a great part of it to remain in the case when the piston rod is drawn out to its utmost extent: accordingly, in this pump, it acts in this respect as well as could be wished *. A notch is cut out of the case at I, to allow the teeth of the wheel to take into those of the rack; and to keep the case firmly in its place, little notches are cut in the upper edge of it, into which the contiguous parts of the pillars are let, and it is secured so by wedges 2, 2, underneath. It will be known that the case of the rack has its due position when, the arm G being taken off, both the rack and the piston rod, pulled out to their limit, are

* By this contrivance of fixing the barrel of the pump horizontal and its rack underneath the barrel, it is made so portable that I have packed it (the gage glass and receiver being taken off) in a box two feet long, eighteen inches wide and seven in depth; and it should be remembered, that the most operose parts of it here described are the frame and machinery necessary to render a pump with *so long a cylinder* portable; a great part of which machinery, if it were not portable, would not be spared, but merely exchanged for the huge frame of those so constructed.

are found to be parallel. The pillars are made as ſhort as poſſible; to favour which, the frame M has a furrow cut in the middle of it under the wheel I, to let the teeth of the wheel deſcend almoſt to the table on which the machine reſts; and the pump barrel is placed as near as may be to the rack.

On the upper part of the box containing the collar of leathers, is a projecting part of the metal, in the ſhape of a cube, forming a little pedeſtal Q: on this is placed the valve f; from beneath which deſcends a ſtraight duct into the barrel without penetrating the box: the form of the parts of this valve (all made of braſs and of the ſize of the originals belonging to the pump) is repreſented in fig. 4. in a vertical ſection. A A is a ſquare plate (to be taken off, if it ſhould require to be ground and poliſhed anew in contact with the valve;) which is faſtened on the pedeſtal with cement; it has a hole in the middle, being the opening of the duct, in which is inſerted the little elevated pipe *c*, to be occaſionally taken out; whoſe uſe is, to prevent the oil applied to the valve from being blown down into the duct, by the air ruſhing into the barrel: the elevated part of the plate *a a* is circular, and has its upper ſurface made plane and poliſhed, on which reſts the valve D; which is ſo far hollowed within, that only its lower edge, being about $\frac{1}{30}$th of an inch thick, (which is alſo well poliſhed) may be in contact with the plate under it, and alſo that its cavity may riſe above the little pipe:

pipe: the valve is almoſt cylindrical, tapering but a little from the baſe upward, and being laid on the plate with a ſmall drop of oil interpoſed, the hollow cylindrical cap E, very little wider internally than the valve, is put over it, being faſtened down on the projecting circular part of the plate *a a*. To let the air paſs through this cap, three little holes *e*, *e* are made in its ſides, the centers of which are juſt as high as the lower edge of the valve D, when it is raiſed to touch the top of the cap; the holes being higher than the plate under the valve, that the oil may not run out by them. When this valve is found to admit air into the barrel, it is occaſioned either by the oil's being blown away, or ſome particle of duſt, &c. getting between it and the plate, (which would produce the ſame effect in any valve) and is remedied by taking it off, wiping it clean and applying another drop of oil: the greater the quantity of air is, which paſſes by the valve, the more is the oil diſſipated, and conſequently this chiefly happens in the beginning of the exhauſtion, when much air is drawn from the receiver, and thrown out of the barrel at each ſtroke; ſo that whenever great rarefaction is requiſite, I often found it convenient towards the end of the operation to apply a freſh drop of oil to the valve, keeping the piſton in the mean time elevated to the top of the barrel whilſt the valve is taken off, until it be replaced; which is done in an inſtant: thus it will perform perfectly well, if quite clean and free from duſt; but as the ſmalleſt particle of dirt or mucus (which is apt to be produced from the oil's corroding the

the braſs and becoming clammy) will render the valve not air-tight, I am therefore perſuaded that no valve will ſo perfectly or certainly exclude air as a ſtop-cock; and this I take to be the chief reaſon why Mr. Smeaton's pump, as improved by Meſſrs. Kaas's and Hurter's contrivance for raiſing the valve at the bottom of the barrel, does not in practice anſwer as well as any other: for if ſome air did not return into the receiver by that valve, in pumps on his conſtruction, it would be hard to tell why it ſhould not perform as well as a pump of any other conſtruction.

To the bottom of the barrel is faſtened, by four ſcrews paſſed through its prominent rim, the circular plate R, forming, in part, the ſhell of the cock S, and which has the high ridge T on the back of it; all theſe being only one piece of metal, which is repreſented ſeparately in fig. 5, and was caſt in that form: the round plate is about $\frac{1}{4}$th of an inch thick, but the cavity of the cock intrudes ſo far on this that, when the key of the cock is put in, the thickneſs of the plate in the part directly over the key, where the ducts open into the barrel, is not more than $\frac{1}{8}$th of an inch: the length of the ſhell of the cock is three inches; that of the key $\frac{1}{8}$th of an inch leſs: the diameter of the key at the thicker extremity is 1 $\frac{4}{10}$ths of an inch, and at the ſmaller end 1 $\frac{1}{4}$th of an inch. It is turned by the handle *u*, faſtened on its axis as near to the end of the ſhell as may be, viz at the diſtance of $\frac{1}{4}$th of an inch. Care

was taken that the metal of the cock ſhould be free from pores, by which if air were admitted in the working, it would be very hard to diſcover it, as this might take place only in *certain poſitions* of the key; and the ointment might ſometimes prevent and ſometimes ſuffer it, ſo that it might elude trials; the cock was alſo ſo truly and ſmoothly ground as to produce an intimate contact of the key and ſhell throughout, (for air will penetrate where liquids would not) it was alſo made of a true conical ſhape, its ſides being perfectly ſtrait from end to end. The cock muſt be lubricated and made air-tight by ointment *, and as all oil or greaſy ointment has an acid in it, (of which perhaps it can never be diveſted without deſtroying its lubricity) which corrodes the braſs, and ſtiffens the oil or ointment itſelf, by impregnating it with green ruſt or verdegris, I found it neceſſary, after the cock was finiſhed, to have the key and the inſide of the ſhell coated with tin †.

THE

* This I have made of one part common roſin, one part oil, and one part and a half freſh ſuet: the oil and roſin is firſt melted, and when a little cooled, the ſuet is added, that the heat requiſite to melt the roſin may not burn the fibrous part of the ſuet and deſtoy its firmneſs: more oil is to be added in cold than in warm weather. The quality of the ointment for the cock is of the utmoſt conſequence; for if ever the parts of the metal of the cock come into immediate contact, it will not be air-faſt; oil will not render it ſo, (nor conſequently would a valve) but the ointment muſt be ſtiff and adheſive; yet not too ſtiff, as then it would be hard to turn the key, and it could not be diſtinguiſhed whether its ſtiffneſs was owing to the ointment, or to the friction of the parts of the metal getting into immediate contact, which would be pernicious.

† This was done by making the metal very clean and bright by rubbing with whiting and water; and having heated it as hot as boiling watet, and preſerved it ſo,

THE key of the cock terminates in a little knob $x$, fig. 2. againſt which the end of the thin ſpring lever $y$, preſſes to keep the key conſtantly firm in its ſhell: this ſpring is made to urge onward the key with any degree of force requiſite, by the ſcrew at $y$, ſcrewed through the outer part of the little arch or frame, which frame is itſelf faſtened by ſcrews on the prominent ring of the barrel, as appears at $z$, fig. 2. The lever has a little ridge or elevated part, which reſts in a notch in the frame; by which the lever is fixed in its proper place, the notch being the fulcrum: by withdrawing the ſcrew, the ridge may be raiſed out of the notch, and the lever pulled back from the knob, to let the key be taken out when it requires more ointment; which will be known when it has worked into the ſhell nearly to its limit; and this ſhould be

 carefully

ſo, I rubbed the parts to be tinned very well for half an hour, or more, with a linen rag wetted with diſtilled vinegar, in which had been boiled ſome ſalammoniac, together with an amalgam of quickſilver and tin; 'till the metal was every where well coated with the amalgam; then wiping off the looſe particles, I heated the metal in the fire, 'till in the dark, it was juſt beginning to appear red hot; with this heat the mercury evaporated, leaving a very hard coat of tin on the metal, without in the leaſt injuring its ſhape or poliſh; this alſo prevented the key and ſhell of the cock from tearing one another by friction, which would certainly ſpoil the cock, as frequently happens with ſoft braſs.

The inſide of the barrel (for reaſons hereafter given) ſhould be tinned in the ſame manner; but it ſhould, before it is at firſt poliſhed, be heated equally red in the fire, and ſuffered to cool equally and gradually, that it may not alter its ſhape when heated again in tinning. Any other method of tinning it, but this, would be both difficult and hazardous.

carefully learned, by marking how far it can be inſerted into the ſhell without any ointment interpoſed. The form of the key and its lever is exhibited in fig. 6. in an horizontal ſection through the middle of them.

THROUGH the ſhell of this cock are two round perforations for two ducts through the cock, each, one inch diſtant from the other, and the ſame from the end of the cock on either ſide: they are in a plane or ſection paſſing through the axis of the key, and alſo through the axis of the barrel; and both paſs through the ridge of metal T, at the back of the ſhell. The duct next the ſmaller end of the key (being a part of the duct communicating with the receiver) is in diameter $\frac{1}{4}$th and the other duct is only $\frac{1}{8}$th of an inch: through the key alſo are ducts anſwering to the perforations in the ſhell; but the ducts in the key are not both in the ſame ſection of it, but one of them is at right angles to the other; ſo that when one of the ducts through the cock is open, the other will be always ſhut, and vice verſa.

THERE is a continuation of each of thoſe ducts formed in the piece of metal V, which is joined (by cement interpoſed) to the ridge of the ſhell of the cock by four ſcrews *g*, *g*, fig. 1, by two openings (into the two ducts in the piece of metal) oppoſite to thoſe in the ridge; and theſe ducts in the piece

piece V, have two other orifices at *a* and *c*, where the two pipes *a b*, fig. 1, and *c d*, fig. 2. communicate with the two canals in the piece of metal, being connected with them only by the help of cement, that the barrel with its cock may be occasionally disjoined from them: thus a separate communication is formed between each of the pipes and the barrel.

THE pipe *a b*, is only $\frac{1}{10}$th of an inch in diameter, except at its orifices which are widened; one of them is connected at *b*, with a duct formed in the piece of metal *k*, attached to the box of leathers C, at the top of the barrel, which duct turning in an angle, without penetrating the box, opens into the barrel: this pipe and duct are joined by a simple application of their orifices, which are made in the contiguous sides of both, and the joint made air-tight by cement melted around with a blow pipe; and the same might be effected by the pressure of a screw closing the surfaces, with oiled leather interposed. By this pipe, when the valve is shut, and the key of the cock so placed that the communication of this pipe with the bottom of the barrel is open, if the piston be depressed from the top, all the air which is *under* it will be forced to pass, by this pipe, into thebarrel *above* the piston; and vice versa, if the piston be elevated from the bottom; so that according to the motion of the piston, the air under or over it within the barrel is made to change its place, and to circulate from the

the ſpace under or above the piſton, to the contrary; from which effect of this pipe, I call it the *circulating pipe*.

THE other pipe or duct is repreſented at *c d*, fig. 2, which exhibits a back view of the pump: its extremity *c*, enters the block of metal V, to communicate with the duct therein, and ſo with that through the cock into the barrel: its end *c* has a wing ſoldered to it, by which it is firmly ſcrewed to the piece V, this being neceſſary, leſt the cement, by which alone the joint there is made air-faſt, ſhould be cracked by any ſhock moving the barrel; or it might perhaps be ſecured by the ſcrew with only leather interpoſed; this duct is a very wide one, that the air may the ſooner paſs through it; it has a turn at right angles at *d*, and another at *e*, from whence it extends under the pillar B, and pump-plate C D, through the middle of which it riſes at A; it has a branch turning at right angles from A, under the pump-plate, the end of which terminates in a round orifice with an inſide ſcrew, that by means of a pipe, furniſhed with a ſtop-cock, or otherwiſe, another pump-plate and receiver, or ſeveral of them, may be connected with it, being laid on the ſame table which ſupports the pump: when ſuch are not uſed, the orifice is cloſed with a ſtop-ſcrew as at D. From this pipe riſes a branch E, inſerted into the top of the braſs cap F of the glaſs veſſel Y, and opening into the veſſel by a duct made in the thick plate of the cap. G, is a reduced barometer tube to be filled

filled in the most perfect manner with mercury, and immersed into a pool of merc$^y$ in the bottom of the glass vessel. The interval between the tube and the neck of the vessel is closed by cement, which, as the neck must be a good deal wider than the tube, is effected by a deep ring (I) fitted to the tube, having a round plate at the bottom of it; which being let down on the tube, after it has been immersed in the cistern, is joined with cement to the top of the cap. The tube was easily immerged in the mercury within the vessel, by covering its open end, and sustaining the merc$^y$ in it by a little plate or scale of iron (P) fig. 7. having two threads tied to it through two holes made near its edges; which threads were grasped together with the top of the tube between the fingers, and the tube was inverted and let down into the merc$^y$ in the vessel: the little plate was then pulled up by one of the threads, it being made so small as to pass through the neck of the glass while the tube was within it and remained immersed in the merc$^y$ *: the vessel was then closed at the top with melted cement; and as it communicates by the pipe E with the conduit pipe, it is exhausted with the receiver, and the merc$^y$ in the tube will sink as the rarefaction advances: if a perfect

* I thought this the best way of fixing the reduced barometer, for if there were a separate vessel, as a cistern, for the merc$^y$, and a receiver placed over it and the tube, the eye, when on a level with the surface of the stagnant merc$^y$, could not see the altitude of that in the tube, with precision, through two glasses.

fect vacuum could be made in the rec$^{r}$ and gage-vessel, it would sink more or less *beneath* the level of the surrounding merc$^{y}$, as the tube is narrower or wider, even so as to disappear, if the tube were very narrow; so that it must not be less than $\frac{3}{10}$ths of an inch in diameter; but it would be better if it were $\frac{4}{10}$ths. If it were observed how much the merc$^{y}$, in a tube open at both ends, would sink beneath the level of that in a cistern, in the open air, it might be pretty nearly estimated how great is the rarefaction in this gage vessel and consequently in the rec$^{r}$.

THIS reduced barometer is the ordinary gage I used, by which a person accustomed to observe it may know what is nearly the rarefaction when it does not exceed two or three thousand times; for which purpose there should be marks made with a file on the outside of the tube, dividing it into inches and decimal parts: if the common whole barom$^{r}$ gage, and this reduced one, were applied to the pump together, the altitude of the merc$^{y}$ in the latter would be equal to the difference between that of the former and a standard barom$^{r}$. When the merc$^{y}$, having sunk to the bottom of this short tube, rises to the top again on admission of air, all the invisible air bubbles which were in it, will ascend and form one air bubble at the top, which will be the less, and the gage the more exact, as the tube had been more perfectly filled, and this will also shew how far the ordinary Torricellian vacuum is from being

so

ſo perfect as it is commonly ſuppoſed, for there will perhaps always be ſuch an air-bubble formed, be the tube ever ſo carefully filled: in that mentioned in the ſubſequent trials however, the bubble was not bigger than a pin's point, and ſcarce viſible.

If after exhauſtion the air were let ſuddenly into the rec$^r$ and gage-veſſel, the merc$^y$ would be forced up into the tube with ſuch violence as certainly to knock the top off it, or to ſplit it; to prevent which, the cock is placed at H, to ſtop the communication of the rec$^r$ duct with the branch of it which goes to the gage-glaſs, whenever it is requiſite to let air ſuddenly into the rec$^r$: when this cock is not ſhut, the communication between the rec$^r$ and gage-veſſel muſt never be opened, (if the latter has been exhauſted and the merc$^y$ has ſubſided in the tube) 'till the piſton is previouſly put down to the bottom, and the rec$^r$ is exhauſted. It would be a great improvement of this machine, if another ſuch cock were placed between this one and the rec$^r$, to ſtop occaſionally the main duct between the barrel and rec$^r$; by which the rec$^r$ would be doubly fortified againſt the intruſion of air, and the cock attached to the barrel might then have its key taken out, when it requires freſh ointment to be applied; which will often be neceſſary, when it muſt be turned many times during the exhauſtion of a large rec$^r$, or when one is to be kept exhauſted many days, and it may be requiſite frequently in that time to pump out air which

 might

might have forced an entrance into the rec$^{r}$. This can't be done in my pump here deſcribed for want of this ſecond cock, which might at firſt have been eaſily added.

The gage-glaſs or veſſel is ſupported by the pillar B, which is ſo high, as that the eye of the operator, looking over the barrel, may be on a level with the ſurface of the merc$^{y}$ in the gage-veſſel; it terminates in a deep cup W, to receive the narrow bottom of this veſſel, which is fixed in it with cement: the pillar is fixed upon the duct of the rec$^{r}$ by two ſcrews which paſs through the iron frame underneath, and alſo through the ſides of the duct, which are ſo thick as to admit holes for the ſcrews to be made through them, without the channel of the duct; by which both the pillar and the duct are made firm.

If a ſyphon-gage ſhould be preferred to the reduced bar$^{r}$, this pillar would ſupport it, and the pipe E might be connected with its open end. I have preferred the former, becauſe in it the foul, confined, or factitious air, which may be in the rec$^{r}$, can never get into the tube, and make its ſides and alſo the merc$^{y}$ in it foul, preventing its motion in the tube and equilibrium; as it ever will do in time in the ſyphon or common bar$^{r}$ gage; ſo that this little barom$^{r}$ always acts as well as at firſt. To apply a whole bar$^{r}$ as a gage to this pump, when

when placed on a common table which is too low; let a metal pipe connected with the rec[r] at C, or D, fig. 2. have an arm rising upwards to the height neceffary to connect it with the open top of the bar[r] tube, whofe ciftern may be fupported by a board faftened below to the frame of the table. Thus every neceffity will be prevented for conftructing the pump with an unportable frame.

In order to make each of the ducts, which have now been defcribed, communicate alternately with the barrel, it is neceffary that the key of the cock fhould receive a motion of one quarter of a turn, the ducts in it being at right angles to each other; and confequently it muft have detents to confine it to that motion: this is effected by a pin *n*, fixed perpendicularly in the back of the handle *u*, fig. 1. which pin, when the handle is put on the fquare end of the key (and fecured there by a winged nut) defcribes a quadrantal arch under the fhell of the cock, where there is juft room to allow fuch a motion of the pin, a part of the ridge of metal at the back of the cock, being hollowed out for that purpofe; and care was taken that the ducts in the key, when at the limits of its due motion, exactly correfponded with the holes in the fhell; the key not being pierced 'till the handle was fittted on, and thefe limits afcertained. The joinings of the cock to the barrel, and

of the piece of metal to the cock, as alfo of the ducts to that piece of metal, are made air-tight by melted cement interpofed between them *.

THE

* The parts to be joined were firft made very clean and bright, and then heated fo much as to melt the cement quite fluid; fome of it being thus fmeared on the whole of the furfaces which were to be applied together, before they were joined; as otherwife it would not penetrate into an extenfive joint, efpecially if the metal were too cold, for the cement would grow folid in its paffage; nor would it intimately cohere with either glafs or metal lefs hot. The cement I ufed for this purpofe was made of about two parts of common refin and one part bees-wax, melted together, which anfwered well enough: this I alfo melted, with an iron moderately hot, round the edges of the rec^r on the plate, both being previoufly warmed; when I wanted the rec^r to be permanently air-faft, or when from its fides being too weak or of an improper fhape, there was danger that being exhaufted, its fides might change their form by the great preffure of the external air, in which cafe fofter cement would, by yielding, admit air.

Whenever it is neceffary to open the barrel to clean it, the pifton is to be firft raifed to the top, the nut to be then unfcrewed from the end of the pifton rod, the arm of the rack to be taken off, and the fcrews faftening the box of leathers to the end of the pump, to be taken out; then with a hot iron, or rather a candle and blow pipe, melt the cement joining the circulating-pipe to the piece of metal attached to the box, (or unfcrew them if joined by a fcrew.) The box of leathers may then be taken off, and the pifton extracted, which, with the barrel, &c. being cleaned, the parts may be replaced without disjoining any other part of the pump. N. B. The leathers of the pifton having been at firft treated as before directed, frefh hog's-lard would be beft to lubricate its edges with, afterwards; for if oil were ufed for this purpofe (at leaft copioufly) fome of it would get into the holes of the cock, and making the ointment of it too foft, it would admit air. Alfo after ointment has been put on the cock, and the key has been often turned to fpread it evenly, the key, before the pump is worked, muft be taken out; and the mouths of the ducts in it, cleared of the ointment by a pin, and alfo of thofe in the fhell, by a crooked wire. This is neceffary to any pump conftructed with a cock in place of a valve.

The action of this pump in exhaufting is as follows: The pifton being at the bottom, and the key of the cock turned to its limit on that fide by which the communication is open between the barrel and rec$^r$, and confequently that with the circulating pipe clofed, the pifton being then raifed to the top of the barrel, difcharges the air in it through the valve, and that in the rec$^r$ rufhes into the barrel; the key being now turned to its limit on the other fide, the communication with the rec$^r$ is clofed, and that with the circulating pipe opened; while it is kept fo, the pifton is depreffed, and drives the air (which had paffed from the rec$^r$ into the barrel, and was left there on turning the key, and fo clofing the communication between it and the rec$^r$) into the circulating pipe, and through it into the top of the barrel: the pifton being down to the bottom, and the key again turned to open the paffage to the rec$^r$ and to clofe that with the circulating pipe; if the pifton be again raifed, the air above it will, as before, be thrown out by the valve, which air is no other than what in the former ftroke, had come out of the rec$^r$: for the valve at the top clofing, as foon as the pifton began to defcend, excluded all entrance of the external air into the barrel. As the pifton rifes, more air will pafs from the rec$^r$ into the barrel under it, which on turning the key, and depreffing the pifton, is by the circulating pipe conveyed to the top of the barrel, to be pumped out through the valve on raifing the pifton as before. Thus the ftrokes be-

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ing repeated, ſome air will come every time from the rec$^{r}$ into the barrel, 'till that in the rec$^{r}$ is as rare as the air in the barrel would be, when the piſton is raiſed to the top; ſuppoſing no communication to exiſt between the barrel and the rec$^{r}$, nor any more air to be under the piſton when elevated to the top, than there was when it was at the bottom.

This pump acts likewiſe as a condenſing engine, without any other additional apparatus than that common to all; of a frame for keeping down the rec$^{r}$, which in this ſhould conſiſt of an iron bar to be laid under the frame ſupporting the rec$^{r}$ plate; in which bar are faſtened two upright rods, with nuts and ſcrews at their ends, to ſcrew down a croſs-piece preſſing down the rec$^{r}$ in the uſual manner. When the bar is thus laid under the rec$^{r}$ plate, this latter will ſtill be level; for the part of the iron frame of the machine which is under the rec$^{r}$ plate, is higher than that part under the barrel by which it is faſtened with clamps to the table, as before deſcribed; and when the frame of the condenſer is not uſed, a piece of board ſhould be laid under the rec$^{r}$ plate to raiſe it to an horizontal poſition.

The action of this pump in condenſing is as follows: The cock of the gage-veſſel is ſtopt that it may not be burſt; the valve is taken off; the communication of the bottom of the barrel

barrel with the circulating pipe opened by the key of the cock, and the piſton raiſed to the top; the external air then preſſes through this pipe into the bottom of the barrel, which it fills: on opening the rec$^r$ pipe by turning the key (which ſhuts the other pipe) and depreſſing the piſton, the air under it is forced into the rec$^r$. The cock being again turned while the piſton is kept at the bottom. and this again elevated, the external air fills the barrel by the circulating pipe as before, and this on turning the key and depreſſing the piſton, as in the former ſtroke, is forced into the rec$^r$; and the condenſation is in this manner encreaſed by a repetition of the ſtrokes; the degree to which it is carried being eaſily known, even without a gage, by knowing the proportion between the capacity of the barrel and rec$^r$, which the operator ſhould, whether he is exhauſting or condenſing, be always certainly informed of, as otherwiſe he cannot tell how many ſtrokes are requiſite to produce a given degree of rarefaction or condenſation; in which latter operation the full of the barrel of air of the natural denſity, is thrown into the rec$^r$ at every ſtroke; a dangerous operation with a glaſs rec$^r$, eſpecially when large, unleſs it is cloſely graſped in a cage of metal rods.

To let air ſuddenly into the exhauſted rec$^r$, there is a pin faſtened in the end of the rec$^r$ duct (at N, fig. 1.) with cement, by pulling out or looſening which, the air is admitted.

I. HAVE

I HAVE been thus particular in defcribing not only the ftructure of this pump but alfo the reafons of the form of each of its parts, and the circumftances on which depends their right performance: becaufe the ftructure of the machine is novel; and alfo that any artift who might make fuch a one, may be guarded againft any alteration not duly confidered; and as no perfon will ever make exquifite experiments with an air-pump unlefs he is himfelf, qualified to underftand and to rectify little accidents and derangements, to which every machine muft be liable, which is to refift fo fubtil an intruder as air; fo I am fure neither artift nor experimenter (for whom alone this is written) will think me tedious in guarding him againft miftakes, which it would be more tedious to difcover, and far more fo to correct: in truth to make this defcription as ufeful as I wifh, the operator fhould underftand the particulars which are mentioned underneath *.

I PROCEED

* Suppofing every part of the pump to have been made of metal without pores; and that every part and pipe has been feparately tried, by being filled with condenfed air, and fo plunged under water, to fee if the air efcapes through any fecret pore; the barrel alfo joined with its cock, and with the piece of metal attached to it, being thus tried in itfelf, after clofing the mouths of the ducts in the latter, and that every part in itfelf is found air-tight; if then the machine when put together, is found to to be leaky, it muft be fo either in the joints, which are clofed only with cement, or in the cocks, the valve, or pifton; and to difcover where the air intrudes, (and difficult indeed will it be found to exclude it altogether) each part may be tried thus: The valve being taken off, put the pifton down to the bottom, and clofe the bottom by

I PROCEED now to explain the principles on which the pump here defcribed was conftructed, and they are thefe:

1ft, THAT the rarefaction produced in the rec[r] will be by the final action of any pump, if there be no obftacle to the air's

by turning the key fo as to reft at the middle between its limits on either fide by which both its ducts will be ftopt, then elevate the pifton, and have it fixed fo, by putting a bit of wood acrofs between two of the teeth in the rack, which will hinder its defcent: after a long time, if the pifton when let down, can touch the bottom of the barrel, no air is admitted by the pifton. This being afcertained, each of the ducts are next to be tried; in order to which, ftop the hole of the rec[r] pipe in the pump-plate; exhauft the gage-veffel, and ftop its cock, and the barrel cock: if then the merc[y] rifes in the tube, the glafs-veffel itfelf admits air by its cap or duct; which being rectified, open the communication of the gage with the rec[r] pipe by turning the gage-cock; if the merc[y] fhould then rife after a good while, the air has entered at the joint of the rec[r] pipe. Thefe parts being fecured; then, to try the circulating pipe; firft exhauft the gage-glafs; ftop the end of this pipe at the top of the barrel, by disjoining it from the box of leathers, and interpofing a thin plate of metal between its opening and the part *k*, of the box; melt cement about the edges of this little plate, to feal up the orifice of the pipe there, having *previoufly* put down the pifton to the bottom; then after opening the communication of the barrel with the rec[r], mark the height of the merc[y]; elevate the pifton a little, and keeping it fo for a good while that whatever air may have entered by the circulating pipe may diffufe itfelf into the barrel, (to allow which this pipe muft now communicate with the barrel) turn the key very flowly and cautioufly, to let this air pafs into the gage-glafs without endangering its tube, and deprefs the pifton to the bottom, when if any air had intruded by the pipe, the merc[y] will rife above its altitude before marked, fhewing that the joint of the pipe with the piece attached to the barrel cock, was leaky; which being remedied, reftore and fecure the communication of the pipe with the top of the barrel; exhauft the gage-glafs, at the laft ftroke of which procefs, when the pifton is at the top, keep it there, 'till you have fealed with a plate and cement the

air's paſſage, the ſame as that which would be in the cylinder, when the piſton is elevated from the bottom to the top, ſuppoſing there was no communication between the rec$^r$ and cyl$^r$ during ſuch elevation; ſo that if there were a perfect vacuum made in the cyl$^r$ *per ſe*, by raiſing the piſton, the rarefaction in

the hole under the valve; open the communication between the circulating pipe and the barrel, then turn the key back again, and depreſs the piſton to the bottom; obſerve where the merc$^y$ ſtands; turn the key, to join the circulating pipe with the barrel; raiſe the piſton half way and keep it ſo a conſiderable time; then ſlowly open the rec$^r$ duct, and put down the piſton; if the merc$^y$ riſes higher than the mark, air has got in either by the piſton rod, its collar of leathers not having been cloſe enough preſſed to the bottom of the box; or by the top of the pump not cloſed; or by the joint of the circulating pipe with the duct in the box; each of which muſt be examined. If the valve admits air, it will be known by being raiſed during the elevation of the piſton before it gets to the top, when the air has been greatly rarefied in the rec$^r$, or when both the ducts are cloſed by the key.

If it be choſen to let the air gradually into the rec$^r$ without looſening the pin, it may be done with ſafety to the tube of the gage-veſſel, by taking off the valve; and raiſing the piſton half way, 'till the barrel under it is filled with air of the natural denſity; then let the cock be *half* turned, and the piſton raiſed to the top, to rarefy the air under it; the cock may then be cautiouſly turned 'till the air gets into the rec$^r$, the piſton being afterwards put down to force into it what air remains under it: this may be repeated.

If the piſton rod moves ſtiffly through its collar of leathers it will be eaſed by ſmearing the rod all around with ſome oil. The joints, &c. may be made air-faſt, by melting the cement on them with a blow-pipe, or by a knob of metal, fixed on the end of a wire, heated by a blow-pipe.

The cock of the gage-veſſel (and all others uſed) ſhould have the key one inch and $\frac{1}{4}$ long, and its mean diameter $\frac{1}{4}$ of an inch at the leaſt. It cannot be too carefully formed and poliſhed.

in the rec$^r$ would indefinitely approximate to a vacuum; and of consequence,

2dly, THAT the degree of rarefaction in the rec$^r$ can never exceed such rarefaction in the cyl$^r$: from both which it follows,

3dly, THAT the most perfect pump, *c*: *p*, is that in which the most perfect vacuum is made under the elevated piston, in the cyl$^r$ unconnected with any thing else.

THE first position is in fact self-evident, if it be admitted that the elasticity of the air is as its density (and I have reason to believe it has elastic force to expand itself 30,000 times;) for thus, whilever there remains any air, it will have power to diffuse itself out of the rec$^r$ into the cyl$^r$ (if there be no valve to raise, nor any thing to oppose its passage) so long as there is less air in the latter than in the former.

THE second position (or consequence rather) is no less evident; to suppose the contrary, is to suppose that a less elastic force could overcome a greater, or that the rarer air in the rec$^r$ could rush into the denser in the cyl$^r$, which is so manifestly absurd, that it is surprizing the first idea of an air-pump which would strike any one, should not be that which first occurred to me, when I thought of making one; that no air

ſhould be left under the piſton when put down; yet this was certainly not adverted to by Mr. Boyle, nor (which indeed I admire) by Doctor Hooke, who aſſiſted in contriving for him the firſt air-pump; for Mr. Boyle complains that he could not, uſing rec^rs^ of any ſize, make the merc^y^ ſink in his barom^r^-gage to the level of that in the ciſtern, and he attributes this to air caſually intruded, when he might have ſeen that he left it behind in his pump at every ſtroke; for it is manifeſt from the deſcription and figure given of it, that a conſiderable ſpace was left between the bottom of the cyl^r^ and the cock; in which air of the natural denſity would reſt, and for ever limit the degree of exhauſtion; now had this been corrected, his air-pump would exhauſt as perfectly as any ſince made, as will appear hereafter. All who have not attended to this circumſtance *, I ſuppoſe, have imagined, that the air left under the piſton could after paſſing into the rec^r^ be extracted from it again; whereas on the contrary, if we ſuppoſe a perfect vacuum in the rec^r^, and an imperfect one in the cyl^r^, from air left behind at every ſtroke and diffuſed in it, this air would at each ſtroke get into the rec^r^, juſt for the ſame reaſon that in oppoſite circumſtances, it paſſes out of the rec^r^ into the cyl^r^, viz. that it is rarer in the latter: to expect the contrary, is to expect it would miſtake the way it ſhould go.

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* Mr. Smeaton was too ſagacious not to attend to it.

As it is uselefs to attempt to make this plainer *, I proceed to explain the meafures taken to diminifh the quantity of air left under the pifton, in this pump, at each ftroke.

SUPPOSE the cyl$^{r}$ to be open at the top, or the valve to be taken off, which is the fame thing; then, as the pifton fits the bottom of the barrel, there is no fpace left for lodgment of air under it when it is put down and the communication with the ducts is fhut, except the two little cavities in the plate at the bottom, being the holes of the fhell of the cock lying over the key; and thefe will be always full of air of the common denfity, at the inftant when the pump communicates with the rec$^{r}$, for the external air preffes into the top of the barrel, which is fuppofed open, and therefore into the end of the circulating pipe which opens there; confequently as the pifton cannot be put down, unlefs the air under it, which it protrudes in its defcent, be difcharged through this open pipe, fo the outward air having accefs to it, and to the bottom of the barrel (with which it muft communicate during the whole defcent of the pifton) will fill it and any void under the pifton; but when the pifton is at the bottom, and the key is turned, the air in the pipe is cut off from that in the bottom of the barrel, none almoft remaining there, but what is in the little cavities over the key; which air will pafs into the rec$^{r}$ on opening its duct into the barrel;—but if, by a *half* turn of the key ftopping *both* ducts,

* I have proved this by calculation, and it will be farther explained hereafter.

ducts, this air be imprisoned in the barrel and the piston be then raised to the top, the air in the cavities will be expanded in the cyl$^{r}$, and whatever is its rarefaction then, no greater can ever be produced in the rec$^{r}$; but its density then will be to what it was when confined in the cavities, reciprocally as the spaces occupied, or as the contents of those cavities to the whole content of the cyl$^{r}$, that is, the rarefaction will be expressed by the quotient of the latter divided by the former; and this I call the rarefaction produced in the cyl$^{r}$ *per se*: now one of these cavities is $\frac{1}{4}$th, and the other $\frac{1}{6}$th of an inch in diameter; the depth of both being $\frac{1}{8}$th of an inch; so the sum of their contents is about $\frac{9}{1000}$ths of a cubic inch: also the content of the cyl$^{r}$, which is about $13\frac{1}{2}$ inches long under the piston, and two inches in diameter, is nearly 42,4 cubic inches; the quotient of which, divided by the former, is 4711: and this No. expresses the rarefaction in the cyl$^{r}$, and what ought to be produced in the rec$^{r}$ by this pump, if it were even open at the top (in which state it would in fact be the same as Mr. Boyle's original one) but as the piston can hardly be made so exactly to fit and fill the bottom, as not to leave a farther vacuity under it, perhaps equal to $\frac{1}{3}$ of that of the cavities under the plate, so this rarefaction should be reduced $\frac{1}{3}$, viz. to 3530; and if the performance of the instrument depended only on its mechanism, it would not fail of rarefying the air to this degree, every part being made perfectly air-tight.

Accordingly

Accordingly this pump in this ſtate (i. e. the valve being taken off) will ſo exhauſt a rec^r as to make the merc^y in an open tube connected with it riſe as high as and ſometimes higher than that in a barom^r of equal bore, placed parallel to it in the ſame ciſtern, and filled with merc^y as carefully as it could be without boiling it in the tube; while the merc^y ſinks in the mean time in the gage to the level of the external merc^y and even beneath it; and the pear-gage, in the drieſt ſtate of the air and rec^r (in which condition only of the atmoſphere ſo great rarefaction could be effected) will then indicate a rarefaction of between 2000 and 3000 Such limited performance was nearly what this theory promiſed; and I alſo found the reſidual air under the piſton, to elevate the merc^y in the gage ſo much at every ſtroke, when, on turning the key, it was let into a ſmall gage-veſſel (no rec^r being uſed) that it was plainly neceſſary to leſſen the reſiduum of air under the piſton, by applying the circulating-pipe, to tranſlate the air from the ſpace under to that above the piſton; by which the uſe of a valve, either in this or in the bottom of the barrel, was avoided; and at the ſame time, the top of the pump could be covered with a plate and valve, in order to take off the great weight of the air incumbent on the piſton, which makes the exhauſtion by a ſingle barrel (and ſo wide a one) too laborious.

The effect produced by this addition is, that whatever before was the reſidual air under the piſton, is now diminiſhed to ſuch a part

a part of the natural air contained in the circulating-pipe, as the cavities under the piſton are of the content of the whole cyl$^{r}$; i. e. as above ſhewn, to about the 3530th part. Now the croſs ſection of the channel of the circulating pipe, which is ſquare, is only $\frac{1}{10}$th of an inch, and its length 21 inches; its contents are therefore $\frac{210}{1000}$th parts of a cubic inch; of the air in which, only the 3530th part is contained in the cavities under the piſton; i. e. nearly the 16809th part of one cubic inch, or the 712700th part of 42,4 inches (the content of the cyl$^{r}$) which N$^{o}$. will therefore expreſs the meaſure of air left under the piſton, and conſequently the rarefaction in the cyl$^{r}$.

THIS will be eaſily conceived, if it be conſidered, that when the piſton has been raiſed to the top, the valve muſt at that inſtant be open, diſcharging the laſt of the air pumped out of the rec$^{r}$; the circulating pipe as far as the key, will therefore be filled with common air; but when by turning the key of the cock, this pipe is opened into the rarefied air or vacuum under the piſton, the parts of the cyl$^{r}$, both over and under the piſton, are one vacuum connected by this pipe; and then the valve, not preſſed underneath, muſt ſhut, and no air enters above the deſcending piſton, but that which expands itſelf out of the circulating pipe; ſo that there is no air in the whole cyl$^{r}$, over or under the piſton, but what had been contained

tained in the pipe, and is now uniformly diffufed through the cyl$^{r}$: and as both the orifices of the pipe open into the cyl$^{r}$ during the defcent of the pifton, fo when this is at the bottom, the whole of this air is *over* the pifton, except fuch a part of it as is expreffed by the ratio of the content of the cavities under the pifton to that of the cyl$^{r}$.

It has been fhewn, that when the pump was open at the top, and the circulating-pipe confequently ufelefs, fo that the air above and beneath the pifton was of the *natural* denfity; yet in this ftate, the rarefaction was as the capacity of the cyl$^{r}$ to that of the cavities under the pifton; but as the air is rarer or denfer in the cyl$^{r}$, it muft be fo alfo in the cavities: and it will by the addition of the circulating-pipe and valve, be rarer in both thefe, in the proportion of the capacity of the cyl$^{r}$ to that of the circulating-pipe (for the air in the latter being diffufed in the cyl$^{r}$ will be rarer or denfer there, as the cyl$^{r}$ is larger or fmaller;) fo that the rarefaction now will be in a ratio compounded of the ratio of the content of the cyl$^{r}$, to that of the cavities under the pifton, and of the ratio of the content of the cyl$^{r}$ to that of the circulating-pipe: for the refidual air under the pifton is inverfely in this compound ratio, and the rarefaction is inverfely as fuch refiduum.

However fince either the valve, or cover of the pump, or the collar of the pifton, will always admit fome air, as the

piſton deſcends, frequently (in my trials) ſo much as the 50th part of the whole capacity of the cyl$^r$, the contents of the circulating-pipe of air muſt be ſuppoſed as encreaſed to that quantity; and the ſecond ratio above mentioned, of the cyl$^r$ to the pipe, muſt be taken as that of the cyl$^r$ to the 50th part of its own capacity; and according to this, the utmoſt rarefaction which could even by this theory be produced, would be about 176500 times; and this the pump would produce, ſuppoſing the piſton to throw up all the air above it, and no external air to intrude unleſs ſome other principle operated to prevent it. Alas! it falls far ſhort of this perfection; and as I have never found any reaſon to ſuſpect, that the piſton left air behind it adhering to the cyl$^r$, nor that any intruded by cocks or joints, in ſuch quantity as to occaſion ſo ſad a defect in its performance (but the contrary as will appear hereafter) this defect cannot, as I conceive, ariſe from the mechaniſm of the pump, but from other cauſes.

It is well known how much any moiſture, or any ſubſtance capable of generating a ſupply of aeriform fluids, either permanently elaſtic under the ordinary preſſure of the atmoſphere, or ſuch only in vacuo, will prevent exhauſtion, and occaſion a contradiction in the gages, by which its degree is indicated. I have conſidered and tried their various effects, having three gages applied to the pump together, viz. a common ſtrait barom$^r$-tube, in which the merc$^y$ aſcended, the reduced barom$^r$-tube,

tube, in which it defcended, and Mr. Smeaton's pear-gage accurately graduated; aud when I knew there was none of the above-mentioned caufes to create the great and furprifing variations, which at different times occurred in the pump's exhaufting power, even when the gages agreed fo far that when any one of them indicated a greater or leffer rarefaction, the two others did fo likewife; I was led to look for the caufes of thefe variations, either in the materials of which the pump, &c. confifted, or in the different qualities in the external air, which was in the rec$^r$; and to fufpect, that new and permanently elaftic air is fometimes generated *within* the pump, in the working, and fometimes abforbed or fixed again; and that the quantity of air fo generated, is in certain ftates of the atmofphere and of the pump, fo great, even in a fingle ftroke, as would fill with this factitious air, reduced to the denfity of atmofpheric air, a fpace even greater than that of the vacuities under the pifton, and of confequence to limit the exhauftion of the rec$^r$ even within what the pump may be fuppofed to effect, without the addition of the valve and circulating-pipe. Now if fuch production of air can be proved to exift, the theory here laid down, may be fo far juft, as the ftructure of the pump is concerned, and defective only with refpect to other principles.

In fourteen feveral trials of exhauftion which I made in the months of July, Auguft and September laft (1795) the air being

 generally

generally very *dry*, the rarefaction produced, as ſhewn by the pear-gage, was, five times, between 3000 and 4000, the merc^y in the barom^r-gage ſtanding at the ſame times always above $\frac{1}{100}$th part of an inch higher than it ſtood in a ſtandard barom^r of a wider bore, which was filled with merc^y made very hot, as was alſo the tube *, as well as I could fill it without boiling the merc^y in the tube; and the merc^y in the reduced barom^r-gage, ſunk below the level of the ſurrounding merc^y. In the other nine trials, the rarefaction as ſhewn by the pear-gage was from 9000 to 26000; when the merc^y in the barom^r-gage ſtood at $\frac{25}{1000}$ths of an inch higher than that in the ſtandard barom^r, and ſunk in the reduced barom^r ſtill lower than before beneath the ſtagnant merc^y. In ſeveral trials made from the 15th of September following to the 5th of December, when the air was always *moiſt*, I could not raiſe the merc^y in the barom^r-gage to the height of that in the ſtandard barom^r (which ſtood cloſe beſide and parallel to it in the ſame ciſtern) except once, and never ſo high even in the pear-gage as it ſtood in moſt of the former trials: whence it is evident, from the correſpondence between the three gages, that a moiſt atmoſphere prevents the exhauſtion, not only of aqueous

* The tube was placed in a heated gun-barrel, and filled with the merc^y heated on ſand, when filled, it was taken out of the gun-barrel, and being ſo cold, as juſt not to burn my gloves, an air-bubble was moved through it; and the merc^y, as I found by trials, ſtood higher than it ever would do if poured cold into the ſame tube.

ous vapours, but even of permanently elaſtic air from the rec$^{r}$, contrary to what has been generally imagined, viz. that ſuch aqueous vapours would encreaſe the rarefaction as ſhewn by the pear-gage, in the ſame degree as they would diminiſh it, according to the teſtimony of the barom$^{r}$-gage.

The reaſon why mere moiſture in the rec$^{r}$ cannot be pumped out, though it be in the form of elaſtic vapour, when the air is moiſt (for in dry weather it actually can, by long working, as I have often found) I take to be this, that when it is got above the piſton, as ſoon as the valve opens, the preſſure of the external air inſtantly reduces the vapour to water, which ſubſides in a dew on the top of the piſton, and the upper parts of the pump (the little air which gets in through the valve, and by ſuppoſition moiſt, being inſufficient to dry it up) and reſolves into vapour again, when it can paſs by the circulating-pipe, opened below, into the vacuum under the piſton: Thus I ſuppoſe it is kept circulating within the barrel and cannot be diſcharged. But why any permanently elaſtic fluid in the rec$^{r}$ could not, in damp weather, be exhauſted, as it was when the air was dry, is a queſtion of great difficulty. I had long before ſuſpected that air was produced within the pump, notwithſtanding its excellent performance juſt mentioned; of the reality of which, from the agreement of the gages, and chiefly from the electrical phænomena (to be hereafter recited) I could not

ſee

fee the leaft ground for doubt; and am perfuaded, that fuch factitious air is generated more copioufly, by the moifture, or fome quality in the atmofpheric air in the rec$^{r}$, in damp weather, than when the air is dry.

An opinion or rule given without a reafon, refts only on the authority of the dictator: that this may not reft on mine, I muft beg leave to relate on what it is founded; for the fact, if it be one, is of the laft confequence to the perfection of the machine, as indicating a new principle, with refpect to which it ought to be conftructed. I muft premife, that in making the following obfervations I ufed no other rec$^{r}$ than a fmall glafs veffel, covering a reduced barom$^{r}$-gage, whofe capacity, together with that of the ducts of the rec$^{r}$ (which conftitute a part of the contents of every veffel to be exhaufted) was only about eight cubic inches; for the fmaller the recipient is, the greater and more diftinguifhable by the eye, will be the afcent or defcent of the merc$^{y}$ in the gage, on the addition or fubtraction of a given quantity of air. The merc$^{y}$ in the gage being by exhauftion brought down within one inch of the level of that in the ciftern, which was always done, the following effects were produced in working the pump; which I noted a great many times to have happened invariably.

1ft, When

1ſt, WHEN the piſton was ſeveral times raiſed to the top, and depreſſed again without turning the cock; the rec$^{r}$-pipe being conſtantly kept open; at every ſuch elevation or ſtroke, the mercy roſe a little in the gage; and generally in ſix ſtrokes about $\frac{1}{7}$th of an inch. In theſe circumſtances, ſome air remaining in the rec$^{r}$, was at each ſtroke, drawn into the barrel, as the piſton roſe, and returned again when it was depreſſed.

2dly, WHEN the rec$^{r}$-duct and circulating duct were cloſed by a half turn of the key, the piſton being previouſly put down, and the ſame number of ſtrokes were repeated, then on opening the communication with the gage, after depreſſing the piſton, the mercy did not riſe nor fall in the gage; but when, after the communication with the gage was open, the piſton was once more raiſed and depreſſed, the mercy roſe much more than it did at *any other* ſingle ſtroke, made when the recr-pipe was open. In theſe circumſtances there was no air in the barrel, during the motion of the piſton, except in the laſt ſtroke, by which alone the mercy was raiſed.

3dly, WHEN the mercy was at the *ſtated* height in the gage, before the piſton was raiſed from the bottom, if it was elevated a part of its ſtroke, before the recr and circulating-pipes were ſtopt, by which means a part of the rarefied air in the gage-recr was drawn into the barrel, and impriſoned there on ſtopping the ducts, then, after the piſton had been raiſed and depreſſed

depreffed the fame number of times as before, and the communication of the barrel and gage was opened, the mercy was *always* found to ftand lower than it did at firft before the pifton had been worked; fhewing, as it fhould feem, that there had been an actual fixation or abforption of air; but when another elevation of the pifton had been made, the recr-pipe being open, then the mercy ftood much higher than at firft; as if the air abforbed, had been regenerated with increafe; or as if by the working when the barrel had been clofed, the ingredients for new air had been preparing in it, when a little air from the recr fhould be admitted into it, as a generative ferment.

In all thefe circumftances there was no communication between the external air and that under the pifton or in the recr; and the appearances took place uniformly and repeatedly; and the experiments were all repeated together on different days, with long intervals, and fometimes in a reverfed order: fo that whatever may have been the caufe of the phænomena, it could not have been the irruption of any air; this could never produce thefe *regular* effects; it could only intrude by the pifton; in which cafe it would not always be the fame in quantity, but it would always make the mercy *afcend* in the gage; whereas in the fecond cafe juft mentioned, it did not; and in the third cafe, it always funk in it : moreover as the top of the barrel was in all thefe cafes open (the valve having been

been taken off) and the air preſſed with its whole weight on the top of the piſton, it would be moſt likely to force an entrance by this, when there was the moſt perfect vacuum under it, as in the ſecond caſe; whereas then the merc$^{y}$ never roſe in the gage, which proved that no air had got under the piſton: and in the other caſes, ſince the gage-rec$^{r}$ was ſo ſmall in proportion to the barrel, and the air in it was thirty times rarefied before the piſton was raiſed, and above one hundred and fifty times after it was raiſed to the top, it muſt have been always ſo rare under the piſton as to have favoured the irruption of the air incumbent on it: and if air had been admitted any where but by the piſton or cock, its quantity admitted would be always the ſame in a given time, which would contradict the appearances that took place; however the changes in the gage were computed from the altitude at which it ſtood juſt before the variation.

AND if it ſhould occur, that the aſcent of the merc$^{y}$ in the gage, was cauſed by external air adhering to the ſides of the barrel, and entangled in the oil or ointment there, which was expoſed to the air when the piſton was put down; a part of which air, not brought up by the aſcending piſton as being enveloped in the oil, yet would expand itſelf into the vacuum under the piſton, and remain there until a paſſage was opened for it into the rec$^{r}$; we ſhall find this will not agree with the

appearances; for if this circumftance took place at all, it would do fo equally in every ftroke and in all the cafes mentioned; whereas it happened only in the firft cafe; in the fecond it did not; and in the third the contrary effect occurred. Moreover, the fame phænomena were exhibited, when the pump was covered by the valve, and none but greatly rarefied air was over the pifton. It muft be remembered, that all the air which once got under the pifton, muft always have remained there until it paffed into the rec^r; and would, if it had been produced as by this fuppofition, accumulate in every ftroke. Neither was this furreptitious air owing to the foulnefs of the barrel, it being both foul and equally fo in the circumftances in which this air raifed the merc^y in the gage; in thofe in which it did not, and in thofe in which the merc^y funk in it; and after the barrel was cleaned, the effects were the fame as before.

It feems therefore, on the view of thefe facts, to be a neceffary conclufion, that the caufe of the phænomena, is to be looked for in the barrel itfelf, and in this, from the effect produced by the *motion of the pifton;* which effect was declared by the gage to be fometimes a production of air *de novo*, and fometimes an extinction or abforption of it again.

To underftand thefe effects, let it be confidered, that though the pump barrel be perfectly clean, and the pifton leathers be even

even new, and lubricated with the cleaneſt oil, yet by a ſingle ſtroke, the oil will be tinged of a greeniſh colour from its having corroded or diſſolved a portion of the braſs. Braſs is a compoſition of copper and zinc, either of which, being diſſolved by the vitriolic acid, emits inflammable air; and diſſolved by the aerial or vegetable acid, will (I ſuppoſe) produce ſome kind of permanently elaſtic air; here ſuch ſolution of the braſs is manifeſt, and why, at every ſtroke of the piſton, air ſhould be generated; and alſo why I have often found more of this air to be produced in the pump (and the degree of rarefaction it could effect to be leſs) when it was clean than when dirty; as the oil being, when foul, more ſaturated, could diſſolve leſs of the braſs; and alſo that oil proved a worſe ſubſtance to lubricate the piſton than hog's-lard, becauſe (as I apprehend) the fluidity of the oil allowed every particle of it ſucceſſively, to come in contact with the barrel, and to diſſolve more of the metal; which could in a leſs degree happen with the lard, from its ſtiffneſs; neither is it hard to conceive that the ſolution of the metal, and conſequently the quantity of factitious air produced by it, ſhould be more copious in a moiſt atmoſphere than in a dry one; when it is conſidered that *ſales non agunt niſi ſoluti;* and that all metals are in damp weather moſt apt to tarniſh and contract ruſt, which is a ſuperficial ſolution of them. I believe alſo that air made moiſt not by what is called veſicular, but by diſſolved vapour (in which latter ſtate I found it to be

 moſt

moſt detrimental to the pump's performance) is more impregnated with an acid principle; unleſs we may ſuppoſe that mere water diſſolves other metals as well as iron: And this with what has preceded, will perhaps account for the different powers of the machine in different ſtates of the air; and for its general failure in the perfection to be expected from the foregoing theory *.

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* The lower plate of the piſton was made of iron; and water or moiſt vapour will diſſolve or decompoſe iron; by which ſolution inflammable air is always emitted: whether this might have taken place in the preſent inſtance I know not, nor whether mere moiſture in the air, free from any acid, could act on the braſs as on iron, when aſſiſted by friction, or could diſpoſe the oil or ointment to act on it, and to produce by a kind of calcination any decompoſition of either the oil, or metal or water: what is certain is, that air is generated in greater quantity by ſome ſuch decompoſition in damp weather, than it is when the air is dry, and this both in ſummer and winter. We are told that iron, without heat, and zinc, charcoal and oils, with heat, will decompoſe water, and ſeparate inflammable air. Could the *friction* of the piſton produce the requiſite heat? we are alſo told that if water were decompoſed into its conſtituent parts, viz. inflammable air and dephlogiſticated air, this latter is or contains an acid principle, which, when uncombined with any other ſubſtance, would act on moſt metals; and ſo the damp air loaded with moiſture only, and not with any adventitious acid in the atmoſphere, may be conceived to produce effects different from thoſe of dry air. The paſſage of the electric matter however, in the atmoſphere, will convert a part of the air into nitrous acid, which diſſolves moſt metals; may not this abound more in the air in moiſt weather; moiſture in the air being generally, if not always, the effect or conſequence of electricity? and may not this be the cauſe of the ruſting of metals by damp air, and of the above-mentioned effects in the pump-barrel? This I believe to be the caſe, becauſe I found that in certain ſtates of the air, much aqueous vapour was introduced by it into the rec[r] without generating any conſiderable quantity of fluid which was permanently elaſtic, and becauſe the diſpoſition of iron, &c. to ruſt is not always the ſame when the moiſture and temperature of the air is the ſame.

The difficulty is, to account for the non-production of air in the second case above-mentioned, and for its apparent extinction in the third. As to the former, there was indeed then almost no air nor humidity in the barrel, and it was separated from whatever might be in the little rec$^r$; and though there was oil, yet I found by the ointment put upon the cocks, which was ever most and soonest turned green in colour near the ducts and outer edges where the air had access to it, than in the other parts, where it had not, that air was necessary to make the oil act on the metal; (nay, perhaps it is not the acid in the oil, but in the air, which is the solvent;) whence in this case, as there was no air in the barrel, so there was no such action on the brass of it. As to the phænomena in the third case, in which I evidently perceived a diminution of air, though I cannot explain it, being ignorant of the chymical analysis of elastic fluids, and of those combinations of airs, which occasion such diminution, and what might be the effect of the friction of the piston in this case, from which resulted all the phænomena; yet what I have stated will, as I think, authorize me to say, that the perfection of the air-pump does not depend only on its mechanism, but also on the materials of which it is made, and that those materials are the best, on which the oleaginous and aerial acid has least action. Accordingly the pewter-metal pump, which I first made, though inferior in the size of the barrel, which was a great disadvantage, yet performed better

better than the brafs one here defcribed, until I added to the latter the circulating-pipe, which gave it the fuperiority: but pewter, though beft to refift the action of the oil, being too foft; the barrel, if made of brafs, fhould be tinned in the infide, in the manner before defcribed, which will fomewhat improve it (and perhaps fubftantial gilding would be ftill better:) but if one were made of glafs, and enclofed in a metal cafe with cement; I think it could be eafily ground and polifhed, and a pifton previoufly formed to fit it, in a metal hollow cylinder or ring of equal bore: fuch a pifton, having its top and bottom plates tinned in the common manner, would I believe conftitute a better pump than any ever yet made, and procure more credit to the theory here laid down.

In that theory I have affumed, that the degree of rarefaction, which can be effected, will depend on that which the pump is capable of making under the pifton, without regard to the fize of the rec$^r$; and as this is not at all the cafe with refpect to air admitted in the working, from the pump's being leaky, which it ever is in a greater or leffer degree; and an objection may therefore arife from the confideration that on opening the communication between the cyl$^r$ and rec$^r$ at every ftroke, any unextracted air under the pifton, and any otherwife intruded, will be together diffufed in the rec$^r$ and cyl$^r$; from whence it may feem, no difference of effect could arife from thefe

thefe, which differ only in the manner of admiffion: to illuftrate this, and to enable the *experimenter* as well as the artift, to determine whether his pump is imperfect from its ftructure or from accident; and how far it ought to be fo from either caufe ; it is neceffary, though I have (reluctantly) been fo diffufe in this account already, to ftate the following particulars:

If air be conftantly and uniformly admitted into the rec$^r$ from this or the machine's not being air-tight, the degree of rarefaction produced by its final action, will depend on the proportion between the capacities of the rec$^r$ and cyl$^r$; for there will always be a refiduum as air is always intruding, and in addition to former refiduums, will be the air admitted in each fucceffive ftroke: in this cafe, the lefs the rec$^r$ is, the more perfect will be the vacuum formed *. Suppofe the rec$^r$ and cyl$^r$ to be equal, and the vacuum made in the latter *per fe* perfect; then half the admitted air will be at length pumped out at every ftroke let the quantity admitted be what it will: for

* Hence it is not the faireft trial of a pump, to ufe a *very* fmall rec$^r$, or to exhauft the gage-tube inftead of a rec$^r$; and it would be the more fallacious, if the refiduum of air under the pifton, might be variable in different ftrokes, from the defective and uncertain performance of valves or of any thing of valve-like ftructure; for as one ftroke with a large cyl$^r$ will nearly exhauft a tube; fo a lucky ftroke or two among many, in which the valves perform their office, will fhew a rarefaction, which might not be produced, where many were requifite to exhauft a larger rec$^r$.

for inſtance, if in the time of each ſtroke, a cubic inch of air intrudes, and the contents of the rec$^r$ and cyl$^r$ be fifty cubic inches each; then the reſiduum in the rec$^r$ after the firſt ſtroke, would be $\frac{1}{2}$ an inch; to which would be added one cubic inch next admitted; and by the ſubſequent ſtroke, half the ſum of theſe would be extracted; i. e. the half of $1\frac{1}{2}$ inches (or $\frac{3}{4}$ of an inch) which the next addition would encreaſe to $1\frac{3}{4}$: ſo that ſuppoſing the rec$^r$ at firſt empty, yet ſome would accumulate in every ſtroke, until the reſiduum would be equal to that intruding during one ſtroke, viz. until both would be equal to two inches; after which one inch would intrude, and one be extracted at every ſtroke: ſo that the air in the rec$^r$ could never be rarefied beyond fifty times, nor finally leſs than to that degree.

And if the cyl$^r$ were twice as large as the rec$^r$ with its ducts; the rec$^r$ remaining as before; and the ſame quantity (one cubic inch) admitted at each ſtroke; then almoſt $\frac{1}{2}$ of this would be drawn into the cyl$^r$ by the laſt ſtroke, and $\frac{1}{2}$ remain in the rec$^r$, when the piſton was raiſed to the top; ſo that now the greateſt rarefaction would be doubled, and equal to one hundred, which, when the rec$^r$ and cyl$^r$ were equal was fifty.

And univerſally, as the capacity of the cyl$^r$ is to that of the rec$^r$, ſo is the whole intruded air during one ſtroke, to the laſt

laſt reſidual air; ſo that the *leſs the rec$^r$ is*, the leſs will be the reſiduum, and conſequently the *greater the rarefaction:* but this is after the pump has exhauſted as much as it can; for in every ſtroke from the commencement to the end, the air in the rec$^r$, whether left in it, or intruded, (or its denſity which is the ſame thing) is to that which remains in it after any ſtroke (or its then denſity) as the ſpace into which it is diffuſed on the elevation of the piſton, i. e. the aggregate or ſum of the capacities of the rec$^r$ and cyl$^r$, is to the primitive ſpace in which it was confined, i. e. to the capacity of the rec$^r$ alone: In which analogy, each of the conſequents, divided by its reſpective antecedent, muſt give the ſame quotient, or ratio, and vice verſa; and ſuch quotients muſt be *in every ſtroke conſtant quantities*, becauſe the two laſt terms of the analogy are ſuch: but the reſidual air after any ſtroke is the primitive air with reſpect to the ſubſequent ſtroke, hence if the firſt reſidual be $\frac{1}{2}$ of the primitive air, the ſecond will be the $\frac{1}{2}$ of $\frac{1}{2}$ (i. e. $\frac{1}{4}$) and the third, $\frac{1}{2}$ of $\frac{1}{2}$ of $\frac{1}{2}$ (i. e. $\frac{1}{8}$) of the primitive air; and any reſidual will be the laſt term of a geometrical progreſſion, the N$^o$. of whoſe terms is the N$^o$. of ſtrokes; each term being ſo often involved or multiplied into itſelf: if the firſt term be as here, the quotient of the rec$^r$ divided by the ſum of the capacities of the rec$^r$ and cyl$^r$, it will expreſs what fractional *part* of the primitive air the next reſidual is; and the progreſſion or ſeries will be fractions and *decreaſing;* and if the firſt term of the ſeries be the quotient

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of the aggregate, of the rec$^r$ and cyl$^r$ divided by the rec$^r$, this quotient will be a whole or mixed N$^o$. expreſſing the *No. of times* the primitive air contains the reſidual, i. e. expreſſing the rarefaction; and it will be the common term of a ſeries reciprocal of the former one and *encreaſing*; the value of correſponding terms in each, being equally above and below unity. This is the common theorem for determining the rarefaction after any N$^o$. of ſtrokes *; but it ſuppoſes a perfect vacuum

* By this theorem two things will eaſily be found, which the experimenter muſt know, viz. what is the rarefaction which ought to be produced by any N$^r$ of ſtrokes, and, and what N$^r$ of ſtrokes are requiſite to produce a certain degree of rarefaction; (for I have found that if the pump does not effect this in a very few more ſtrokes than the theory requires, it will generally be loſt labour to continue to work it, unleſs in dry weather or a dry room, one has hopes of pumping moiſture out of the rec$^r$). Both particulars may be beſt found by the aſcending ſeries; viz. by multiplying the quotient, of the ſum of the contents of the rec$^r$ and cyl$^r$ (in cubical inches) divided by that of the rec$^r$ (which will be a whole or mixed N$^r$, the fractional part of which latter, is to be reduced to a decimal) continually into itſelf, as many times as there are ſtrokes, and throwing away from every product all the decimal figures to the right hand, except two or three, which will occaſion no material error, and much abridge the work; which is alſo farther abridged by multiplying any power, ſo produced, by itſelf, or by any other power thus before found; for the product thus ariſing, will be that power whoſe exponent is the *ſum* of thoſe ſo multiplied; as the cube or third power drawn into itſelf produces the ſixth power; or drawn into the fifth power, produces the eighth power; and ſo in any other. Thus the rarefaction produced by any N$^r$ of ſtrokes will be found, being expreſſed by that product or power, whoſe exponent is the N$^r$ of ſtrokes; and it will alſo be ſeen in the proceſs, what N$^r$ of ſtrokes ſhould produce any given degree of rarefaction; which may alſo be found by the converſe of this proceſs, viz. by *dividing* any greater power found, by any leſſer, for the quotient will be that power whoſe exponent is the *difference*

vacuum to be made under the elevated piſton, and that no external air intrudes; ſo that when either of theſe takes place, the

*difference* of their exponents. But when the rec^r is large, and many ſtrokes will be requiſite to exhauſt it; the operator who muſt calculate what ſhould be the power of his machine, may avail himſelf of the help provided for him by the noble inventor of the table of logarithms: for as in theſe the ſum or difference of any two logar^s is the log^m of the product or quotient of the correſponding natural N^rs; and that the product or quotient of a log^m (multiplied or divided by any N^r) is the log^m of that power or root of the correſponding natural N^r, whoſe exponent is the multiplicator or diviſor of the log^m: ſo whatever is effected by multiplication, diviſion, involution or evolution of natural N^rs, may be performed by addition, ſubtraction, multiplication and diviſion of their log^s. And thus the *quotient* above-mentioned may be found by *ſubtracting* the log^m of the rec^r from that of the aggregate of the rec^r and cyl^r, and then multiplying the remainder by the N^r of ſtrokes of the piſton; for the product will be the log^m of that N^r which expreſſes the rarefaction; alſo to find what N^r of ſtrokes will produce any required rarefaction; take the log^m of the N^r expreſſing this rarefaction; it is plain from what has been ſaid, that this log^m muſt belong to that natural N^r, which is ſuch a power of the aforeſaid quotient as would be produced by the ſame N^r of involutions, as there ſhould be ſtrokes of the piſton employed to produce the rarefaction; and that if this log^m were evolved as many times as we muſt ſuppoſe its root to have been involved; that root would be found which belongs to the original quotient by whoſe involution it was produced; and that if the log^m of the power be divided by the log^m of the root, the quotient will be (from the nature of log^ms) the N^r expreſſing how often it had been involved: there is nothing then to be done ſince we know the log^m of the above-mentioned quotient, which is the root, but to divide by it the log^m of the deſigned rarefaction, and the quotient will be the N_r of ſtrokes of the piſton required.

I inſert this and many other things for the eaſe of thoſe who may be more converſant in experimental chemiſtry than calculation, and to enable ſuch (without recurring to other books) to ſubject the air-pump to a rigorous trial; theſe will alſo be the perſons moſt likely to make the beſt uſe of this machine, on which account, and

the unextracted and intruded air, must be in every stroke added to the residual air in the rec$^r$, as a constant quantity; which will

and to prevent the fault of the artist from being attributed to the structure of the instrument, I shall also beg leave to add what follows:

The quantity of air in measure, that may in any length of time have forced an entrance into the rec$^r$, may be found, and the just allowance made for it in the defect of the pump's performance, by stating, as the height of the merc$^y$ in the standard barom$^r$, is to its ascent or descent in the reduced or standard barom$^r$ gages, in a given time, suppose six hours, so is the whole content of the rec$^r$ and its ducts, to the part thereof which would be filled in six hours with the intruded air, if reduced to the density of atmospheric air. Also, to know what allowance is to be made for such intrusion in the defective altitude of the merc$^y$ in the gages, state, as six hours, is to the time in which one stroke is made (suppose half a minute) so is the ascent or descent of the merc$^y$ in the reduced and standard barom$^r$-gages, in six hours; to the ascent and descent which ought to be occasioned by the air intruded, in the time of one stroke; then the ascent and descent thus found, being diminished or increased according to the ratio of the rec$^r$ to the cyl$^r$, and deducted from and added to the altitude of the merc$^y$ in these different gages, any remaining difference between that altitude, and what exists at the time in the most perfectly filled standard or reduced barom$^r$, is to be attributed to the imperfection of the machine.

If the altitude of the barom$^r$-gage, be referred to that of a standard-barom$^r$ filled with merc$^y$ not boiled in the tube, though it were otherwise poured hot into it, the tube itself being hot, and carfully purged of air by moving an air-bubble through it, the merc$^y$ and tube being perfectly clean, yet the altitude of the merc$^y$ in *such* a standard-barm$^r$ must be supposed to be less than it would be if the tube were perfectly filled, by at least $\frac{25}{1000}$th parts of an inch; because as this air-pump never failed in a favourable state of the air, to raise the merc$^y$ in the gage thus much higher than it stood in a standard-barom$^r$ filled (several times) in the above manner; it is plain this latter will be always imperfectly filled and the height of the merc$^y$ in it deficient, by the above quantity, and I found that it would

will varioufly alter every term in thefe feries, and produce other feries, the terms of which will continually approximate to

would be ftill more deficient if the merc$^y$ were poured cold into the tube. Now fuppofing the altitude of the merc$^y$ in the ftandard to be thirty inches, $\frac{25}{1000}$ths of an inch is the 1200th part of the whole; and if the merc$^y$ in the gage be as high as that in the ftandard, the rarefaction is only 1200; and that in the ordinary Torricellian tube, is, I believe, never greater, but moft commonly lefs than this; though from there being no air bubble apparent at the top of fuch a tube, when on inclining it the merc$^y$ afcends, one might imagine that no elaftic fluid refted above the mer$^y$: for if the tube be filled cold, there will be moifture within it, which will be condenfed into fmall invifible particles by the preffure of the atmofphere when the tube is inclined, but will expand again in elaftic vapour, depreffing the merc$^y$, when by placing the tube vertical, that preffure is removed: and when the tube is filled hot, and fo has no moifture in it, an air-bubble will in the fame circumftances be vifible. This I found however to be partly difcharged, and the merc$^y$ to ftand higher in it, by inclining the tube while in the ciftern (after it had ftood perpendicular and the merc$^y$ had funk to the natural altitude) until it had afcended to the top, and taking it full out of the ciftern, by clofing its end while immerfed in it, with my finger, then having fhaken out a drop of merc$^y$ to allow an air-bubble to be once moved through it, this brought up with it moft part of the air which had been collected in one bubble at the top; after which reftoring the drop which had been taken out, and immerging it again in the ciftern, the merc$^y$ ftood in it higher than before, and I believe from this management it would always do fo. This was done in the prefence of Doctor Young, who from his well-known zeal for the advancement of fcience, was pleafed to be prefent at a trial of the pump's performance; at which time it fo far exhaufted a rec$^r$ as to raife the merc$^y$ in the barom$^r$-gage, near $\frac{1}{50}$th of an inch higher than it ftood at the higheft, in the barom$^r$-tube here mentioned, of equal bore with that of the gage, and ftanding parallel and perpendicular together in the fame ciftern.

If there be in the rec$^r$ no moifture nor vapour expanfible only in vacuo, the pear-gage (as I have always found) will correfpond with both the barom$^r$-gages; and when the rarefaction is near 4000, the eye cannot diftinguifh the difference between

to ſuch numerical part or multiple of the ſum of the ſurreptitious and unextracted air during one ſtroke, as is expreſſed in

tween the height of the merc$^{y}$ in the latter and that in the moſt perfect ſtandard-barom$^{r}$; becauſe the difference in their altitudes is not the hundredth part of an inch; ſo that greater degrees of rarefaction can be known only by the pear-gage; which ſhould therefore be uſed; and it ſhould be of a proper form and accurately graduated. It is a glaſs-veſſel in ſhape ſomewhat like a pear or rather an hydrometer, with a bulb, of a ſize to contain between four and ſix ounces of merc$^{y}$, terminating on either ſide in a tube: that below the bulb (about an inch in length) is open; the upper part or ſtem (about five or ſix inches long) is ſealed hermetically at top; the internal diameter of one half of the length of the ſtem next the bulb, ſhould be about $\frac{1}{8}$th of an inch, and the cavity exactly cylindrical, as likewiſe muſt be that of the upper half; but this latter ſhould be as narrow in the bore as a middle-ſized mercurial thermometer, viz. about $\frac{1}{10}$th of an inch in diameter: if the ſtem were of the ſame dimenſions throughout, it could not, unleſs made inconveniently long, meaſure both ſmall and great degrees of rarefaction: it is eaſily made of the above form, by blowing a bulb on a piece of glaſs-tube, about $\frac{1}{8}$th of an inch in diameter; then drawing out the upper part of it (by the glaſs-blower's lamp) into a ſlender tube, and ſealing its end: or rather by adding to the tube a piece of a thermometer tube. The ſtem is faſtened in a braſs pipe or caſe, having a wide ſlit along its whole length, through which the merc$^{y}$ in the ſtem is ſeen, and the degrees are marked on the caſe. During the exhauſtion, the gage is ſuſpended by a ſlip-wire with its open end over a ciſtern of merc$^{y}$ within the rec$^{r}$, ſo that the air in it is as much rarefied as that in the rec$^{r}$; and when the pump has been wrought as much as is thought proper, the end of the gage is immerged in the merc$^{y}$, which on the *gradual* readmiſſion of the air, will be forced up into the gage, and fill the bulb; all the air which had been left in the gage, riſing to the top, and being reduced nearly to the denſity of the external air; which it would be exactly, if the gage were placed not vertical, but horizontal. Then, as the whole cavity of the gage, is to the part at the top filled only with air; ſo is the primitive air which was in the gage, and alſo in the rec$^{r}$, to the laſt reſiduum in each reſpectively, or ſo is the rarefaction produced; hence, the ratio of the whole content

in the defcending feries by the ratio of the rec$^r$ to the cyl$^r$, or the quotient of the former divided by the latter; and in the

tent of the gage to that of *any part* of the ftem, muft be known, and it is thus found:

Let the whole of the narrow part only of the ftem be filled with merc$^y$, and this carefully fhaken out again, and weighed by the niceft balance; let the fame be again filled together with the wider part of the ftem, as far as it is cylindrical, and the contents weighed as before; then let the whole veffel be quite filled, and the weight of the merc$^y$ it holds be found: fince the capacity of the whole gage is to that of the ftem, or any part of it, as the quantities or the weights of merc$^y$ each contains; and the content of each half of the ftem is thus known, and the ratio of the fame to the whole, and fince each half of the ftem is in itfelf cylindrical, equal parts of the *length* of each feparate fegment, will be equal portions of the *content* of that fegment; i. e. the contents are as the lengths; but the contents, and therefore the lengths, will be inverfely as the rarefaction, when the refidual air in the gage is contained within them; fo that if the whole length be graduated from the upper end to the lower in any N$^r$ of equal divifions, and the rarefaction be known, when the merc$^y$ ftands at the loweft divifion or greateft N$^r$ (which rarefaction is expreffed by the quotient of the weight of the merc$^y$ filling the whole gage, divided by that contained in the whole fegment) then, as the whole N$^r$ of divifions, is to that correfponding rarefaction, fo is *inverfely* any other leffer N$^r$ of divifions, to the rarefaction, when the merc$^y$ will ftand at fuch divifion. This method muft be taken to graduate each half of the ftem feparately, as they are of different diameters; but in eftimating the length of the wider half, as the content of the narrower half muft be added to it, fo the wider part muft be computed to be fo much longer than it is, as the addition of the content of the narrower part would make it, if this were reduced to the fame diameter as that of the wider part.

But if the ftem were to be thus graduated by an arbitrary N$_r$ of divifions marked on it, the rarefaction anfwering to each of them would be expreffed by odd or broken N$^{rs}$ unfit for meafuring it; and it would be difficult, when the merc$^y$ ftands not at any divifion, but between two, to find what may be nearly the rarefaction in

the aſcending ſeries by the reciprocal of the ſame, or by the ratio of the cyl$^{r}$ to the rec$^{r}$. For the air intruded, &c. at each ſtroke,

that experiment; it is therefore neceſſary to graduate the ſtem by a decimal diviſion, expreſſing the rarefaction or reſidual air by 100ths or 1000ths; which may be thus done:

Let, as above, the weight of the whole content of the gage be divided by that of the whole content of that ſegment of the ſtem, which is to be graduated; the quotient will expreſs the rarefaction when the mercy ſtands at the loweſt diviſion or end of the ſegment; then ſay, as that quotient or rarefaction, is to the whole length of the ſegment, meaſured by and expreſſed in equal parts, ſuppoſe hundredth parts of an inch; ſo is inverſely the decimal, centeſimal, or milleſimal N$^{r}$ neareſt to and above the ſaid quotient, to the N$^{r}$ of hundredth parts of an inch (to be meaſured from the top of the ſegment) at which the (loweſt) diviſion ſhould be marked on it, anſwering to ſuch decimal, centeſimal, &c. N$^{r}$ expreſſing the rarefaction, when the mercy will ſtand at that diviſion: and as the ſaid quotient (of the weight of the content of the whole gage, by that of the whole ſegment) to the ſaid length of the ſegment; ſo is the ſecond decimal, centeſimal or milleſimal N$^{r}$ inverſely, the ſecond diviſion to be marked; and ſo on until the whole is graduated.

Example. Let the weight of the mercy contained in the narrower or upper ſegment, be two grains, and that in the whole gage be 1970 grains (which were the meaſures of my gage): the quotient of the latter divided by the former is 985; ſo that when the mercy ſtood at the loweſt diviſion, the rarefaction was 985; the neareſt milleſimal N$^{r}$ to which is 1000: alſo the length from the top of the ſtem which two grains weight of mercy filled, was 141 hundredth parts of an inch: as therefore 985 is to 141, ſo is inverſely 1000 to 138, 88 hundredth parts of an inch; which is the length from the top of the ſtem, at which the diviſion ſhould be made, where the mercy, when ſtationary, would ſhew a rarefaction of 1000. In like manner as 985 : 141 : : inverſely 2000 : 69, 44 hundredth parts of an inch, the length from the top, at which the diviſion anſwering to a rarefaction of 2000 ſhould be made; which will be half the former length: and thus may the reſt of the ſegment be graduated

ſtroke, being the ſame, its quantity muſt at length be directly as the rec$^{r}$; and the quantity remaining after each ſtroke, as the capacity of the rec$^{r}$ to that of the cyl$^{r}$; conſequently the rarefaction the reciprocal of this.

Hence appears the miſchief of leaving any air under the depreſſed piſton; for the whole of it *muſt paſs into the rec$^{r}$* at every ſtroke; and if the rec$_{r}$ be ſmall, the greater will be its denſity there; but if the rec$^{r}$ be large, there muſt be more ſtrokes to exhauſt it, and ſo more additions to the reſidual air in it; alſo leſs of it can be pumped out again: however, though no air were left under the piſton, yet if air intruded from the machine's being leaky, its power in extracting ſuch ſurreptitious air, would not at all correſpond with the ſame in extracting the primitive air in the rec$^{r}$; for with reſpect to this latter, the greateſt rarefaction in the cyl$^{r}$ itſelf is given,



graduated; firſt, either by a continual biſection of the diviſions towards the top (which will be always one extremity of the interval biſected) for ſuch biſection, as it *halves* each length of the ſegment, muſt *double* the rarefaction correſponding to the lower extremity of the portion biſected, theſe portions being inverſely as their correſponding rarefactions; and ſo the leaſt rarefaction (of 1000) would be continually doubled; or, ſecondly, according to the above-mentioned analogy, by dividing the product of the leaſt rarefaction, multiplied by the length of the ſegment (viz. in the above caſe of 985 by 141; or of 1000; by 138,88, which is the ſame) by any greater N$^{rs}$ expreſſing ſuch rarefaction as one would chuſe to mark on the ſcale; for inſtance, by 1500, 2500, &c.: then the quotients will be the lengths from the top, at which theſe rarefactions ſhould be marked. The lower or wider ſegment of the ſtem is to be ſeparately graduated in the very ſame manner.

and ſo likewiſe muſt be ultimately that in the rec$^r$, let its capacity be what it may. In this machine, the air under the piſton being conveyed away by the circulating-pipe, before the communication of the cyl$^r$ with the rec$^r$ is opened, it cannot get into the rec$^r$, and the rarefaction in the cyl$^r$ being as it were indefinitely great, equal as above-mentioned to 176000, that in the rec$^r$ may be indefinitely encreaſed within this limit; whereas the intruded and unextracted air under the piſton (were there any) *would* get into the rec$^r$, and the part of it which could be pumped out, would depend on the proportion between the cyl$^r$ and rec$^r$, juſt as in the caſe of air admitted through leaks in the machine.

It is not therefore here pretended, that the rarefaction could be carried to an unlimited degree, even on the principles of the pump's mechaniſm; and yet perhaps it may be preſumed that, even on theſe, its conſtruction is ſuperior even to that of Mr. Cuthbertſon, the only one which pretends to a power of indefinite exhauſtion: and as it is only from a belief of this, that the machine here deſcribed is publiſhed, ſo I may be permitted to obſerve, (having had no opportunity of aſcertaining by trial the excellence of his, though I believe it is excellent; nor of ſeeing any deſcription of it, but that in the Encyclopædia Britannica, juſt publiſhed here) that I conceive its perfection muſt depend on the ſuppoſed circumſtance of

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no air being ever admitted into the barrel through the valve or through the perforation in the piſton: for if when the valve is open, diſcharging the air pumped out, and the external air is then preſſing on the piſton with its whole weight, any of it ſhould force its way through the piſton; the rec[r] is then open towards the barrel, and it muſt paſs in an incalculable quantity into the rec[r]. Now the piſton in his pump has the duct through it opened at every ſtroke, and it is cloſed again by a conical ſtopple, ſupplying the place of a cock, and made air-tight only by oil; which ſtopple being faſtened cloſe in the piſton only by the force with which the piſton is raiſed, ariſing from friction, this force or preſſure (unleſs the piſton moves more ſtiffly than one lubricated with abundance of oil, may be ſuppoſed to do) may ſometimes be inſufficient to make the ſtopple firm in its ſocket, until it is gradually preſſed by air condenſed above it, and until the valve opens, and the external air reſts on the piſton; ſo that if the piſton be not perfectly air-faſt, ſome of it muſt get through into the rec[r]; and though the friction of the piſton ſhould be *always* ſo great as to prevent this happening, yet if any ſmall particle of dirt ſhould have got between the ſtopple and its cavity, it would remain impacted there, and be likely to render the duct permeable to air: it ſeems therefore too delicate a circumſtance, to reſt the performance of the machine on, that this duct encloſed within the barrel, and opened at every ſtroke, ſhould, at once, be ſo cloſely ſhut

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again, as never to admit air: alſo the baſe of the ſtopple muſt be broad, that it may be eaſily diſengaged from its cavity which enlarges the ſurface or joint that is to be made impervious to air: this ſtopple is in reality a kind of valve, reſting on the extent of its whole conical ſurface as a baſe, and it was before obſerved how difficult it is to make a valve air-tight, when the ſmalleſt ſolid particle of duſt, &c. will prevent the contact of the ſurfaces though ever ſo extenſive, and that the danger of this encreaſes with the enlargement of the ſurface; and that were it not from this natural imperfection of valves, Mr. Smeaton's air-pump ought to be inferior to none; its mode of action being preciſely the ſame as that of Mr. Cuthbertſon, except that in the latter, metallic valves or ſtopples are ſubſtituted for the flexible valves in the former: whereas the excellence of a ſtop-cock is, that the ſurfaces of the key and ſhell are never *ſeparated:* no dirt can get between them, nor oil be blown away; but ſtiff ointment may be applied inſtead of oil, to make them air-faſt: to the ſtop-cock therefore, and the unperforatated piſton, I attribute the excellence of the pump here deſcribed above others conſtituted on the like principle; for in it, though air ſhould get in through the upper valve, &c. it cannot get into the rec$^{r}$; whereas in the others, if air inſinuates through the piſton, it muſt do ſo; and if to prevent this, in Mr. Cuthbertſon's machine, it were provided to have a pool of oil above the piſton, I imagine

it

it would not be a perfect remedy, even though I were mistaken in the apprehension that such abundance of oil, would generate a greater quantity of factitious air: for when the valve or duct in the piston is open, the oil must descend through it with all the impurities that may be in it; and if the oil above the upper valve can descend into the barrel, the impurities in it will be added, which if they adhered to the stopple or valve in the piston, would be likely to occasion its admitting air; also the oil being thus churned in the barrel, would perhaps entangle air, especially when viscid, as it will become by corroding the brass. In this pump, it is not necessary to use oil, especially if the barrel be made of pewter; for then the hog's-lard or ointment used will not lose its lubricity; in fact fluid oil is inadmissible, for it would certainly render the cock, though formed and ground with care (how much more then a valve?) not air-tight; the air forcing a passage even through the oil within the joint, if this be not very close, which in a cock whose key is in continual motion cannot always be; nor is this hard to conceive; for where ever a column of merc$^{y}$ as high as that in the barom$^{r}$, resting over a joint or chasm, could force a passage, the air will do the same, and perhaps more powerfully.

It will appear then that there is no kind of limitation in the pump here described, which is not in any other; for in the

the others, whatever air is left above the piſton undiſcharged, or enters by the valves in the piſton or top of the pump, is diffuſed in the cyl$^{r}$ under the piſton (ſuppoſe it could not get into the rec$^{r}$); and the piſton being put down, whatever cavities are under it, have the ſame quantity of it reſting there, when the rec$^{r}$ is opened, as in this pump; and if air inſinuates by the perforated piſton, it is an inconvenience from which this is ſecure; alſo it condenſes with a ſingle barrel, and without any additional parts, which none other can do. It might be conſtructed with two barrels, and the two cocks might be turned together by one handle, in a manner well known and in uſe; but in this form, it would neither be convenient nor portable; however in the form here deſcribed, the ſingle barrel may be made ſo large, as to exhauſt as faſt as two of uſual ſize; and it is eaſy to conceive from the theory, that the largeneſs of the barrel is every way an advantage, for the cavities under the piſton need not be proportionably enlarged.

As it is ſcarely poſſible to prevent the intruſion of ſome air while the pump is working, and as the quantity ſo intruded, will be proportional to the time of exhauſting, which time would be injudiciouſly lengthened, if the pauſe at each ſtroke were made longer than is neceſſary for the air to paſs from the rec$^{r}$ to the cyl$^{r}$ until its denſity is the ſame in both in any degree of the rarefaction; it would be a deſirable

thing

thing to know whether the air paſſes into the cyl$^{r}$ with a velocity variable according to its denſity, and in what ratio. The time of the air's paſſage cannot be diſcovered by the motion of the merc$^{y}$ in the gage; for when the air is much rarefied, this motion during one ſtroke, is ſo little as to be imperceptible, and when it is greater, the merc$^{y}$ vibrates ſo much in the tube, and undulates ſo long, after the air is paſſed into the barrel, that the term of its paſſage cannot be diſcovered: it muſt be found by reaſoning on phyſical principles; and the enquiry is to be proſecuted on theſe data or aſſumptions, that the meaſures of the rec$^{r}$, duct and cyl$^{r}$ are invariable quantities; and that in the cyl$^{r}$ there is a perfect vacuum, into which the air in the rec$^{r}$ is to expand itſelf, after the piſton is raiſed to the top.

THE conſtruction of this machine was primarily undertaken with a view to diſcover whether the Aurora Borealis is an electrical phænomenon; whether we could in *large* exhauſted veſſels exhibit its genuine appearance; what muſt be the rarity of the air in which it is viſible, and the heights in the atmoſphere, wherein it exiſts, and within which it is (if at all) confined, &c. Theſe enquiries however I did not proſecute; yet the reader will not I hope be diſpleaſed at my extending this long paper ſtill farther by an account of the following experiments relative to them, though they are inconcluſive; eſpecially,

eſpecially, as from the difficulty of making a perfect vacuum in the ſtandard-barom$^r$, and of comparing the altitude of the merc$^y$ which ought to be in it, with that in the gage, I found the exhibition of the genuine Aurora Borealis, the moſt certain mark of great rarefaction, as not requiring a compariſon of the barom$^r$ and pear-gages.

I CONNECTED with the rec$^r$ (which was uſed in the foregoing trials of the pump's exhauſting power, and whoſe capacity was 122 cubic inches) by means of a braſs box fixed on the top of it, one end of a glaſs-tube twenty-one inches long and $\frac{3}{4}$ of an inch in diameter, furniſhed at one end with a braſs cap terminating in an open pipe, which was inſerted laterally into the box of the rec$^r$: the other end of the tube was cloſed ſometimes with a plate of braſs cemented on it, and at other times with a glaſs plate; both which afforded the ſame appearances. The tube was extended horizontally, being ſupported at the end remote from the rec$^r$ by a glaſs-pillar; and it was exhauſted with the rec$^r$; during the proceſs of which, I applied to the tube in the dark, an electrified glaſs-tube, which produced the following appearances in repeated trials.

THE tube ſhewed no electricity from preſenting to it the excited tube, until the rarefaction was about 100; then there appeared within it denſe and bright coruſcations, but they were

were interrupted, not extending the whole length of the tube, neither would they appear when the excited tube was presented to the end, but when to the middle only of the exhausted one; and it was remarkable, that coruscations exactly resembling the above, in their form, &c. except that they appeared when the excited tube *touched any* part of the other one, and that they were so faint as to be scarce visible in a room made quite dark, first *began* to appear, when the rarefaction, as shewn by the pear-gage, was 4000: the standard-barom^r above-mentioned being, at the same time, at 30,1, and the barom^r-gage at 30,12. When the rarefaction was carried beyond this, so as to raise the merc^y in the barom^r-gage, a little higher in several trials, and to advance that shewn by the pear-gage sometimes up to 26000, the appearances were the same, but the gleams of light still fainter; they were a colourless pale white; the coruscations, which were scarce visible, *seemed* conical pointed, waving or streaked, and did not extend the whole length of the tube, exhibiting the most perfect resemblance of the thin pale coloured Aurora Borealis.

In the intermediate degrees of rarefaction, between 100, and 4000 (indicated as above by the *gages*) the phænomena were as follows:

At 300, the presentation of the excited tube *near* to the exhausted one, first occasioned continued flashes in it, filling

its whole length; but this only when presented to the middle, not the ends, this latter first occurred when the rarefaction was greater; and then at every approach and recession of the excited tube, without fresh excitation, even for fifty times together, and with scarce any diminution of brightness to the last, or sign of decay until I ceased to present it, such flashes were produced; they filled the whole tube, but that they were brighter and of smaller diameter at the middle of its length; they were also not only denser but of a more yellow colour, than the faint coruscations before described: but the most distinctive difference between both these kinds, and indicating the great degree of rarefaction necessary for the exhibition of the former was, that when *they* appeared, the excited tube produced no light at all in the other, except at the *first* presentation and *actual contact* with it: from which I concluded (too stupidly and hastily) that the electricity of the former was completely discharged, and that the more perfect vacuum, was a more perfect conductor of electricity, even more so than metals: but though I am yet of opinion that the fact was so, yet it may, for ought I know, be possible, that the tube produced no light after the first presentation, not because it was quite discharged, but because its electricity, lessened by the first discharge, would not pass nor be conducted by the more perfect vacuum in the other tube; or, if it burns, destroys, or changes into nitrous acid the air which conducts it, what remained in

in the tube, &c. may by the firſt exploſion have been ſo conſumed.

But whether this or the contrary be the fact, the experiments have ſatisfied me, that the Aurora Borealis *is* an electrical phænomenon; that, (at leaſt when it is faint and of a pale colour) it cannot appear in air leſs rarefied than near 4000 times *; and conſequently that its neareſt diſtance from the earth is about forty-five miles (according to Doctor Halley's table of the air's rarefaction at different altitudes); that in air rarefied more than 26000 times, it would not be viſible, and therefore its greateſt diſtance is about fifty miles, (by the ſame table): I am notwithſtanding ſenſible it may be leſs or greater: it may be *leſs*, for though my pear-gage ſhewed that degree of rarefaction, I pretend not to ſay what the rarefaction really was; it might be ſix times leſs; but it could not, I think, be known by any gage, what it was, as I am perſuaded, that the difference of altitude between my barom$^{r}$-gage, and that of the moſt perfect barom$^{r}$, would at that time be imperceptible to the eye: it may be *greater*, for a quantity or ſtratum of electric matter $\frac{3}{4}$ of an inch in thickneſs, as in my tube, may be inviſible, when one of the ſame denſity, but many miles



* Perhaps becauſe denſer air, affording too much reſiſtance to its paſſage, i. e. being a worſe conductor, it takes a circuit by the rarer air in the higher regions, from the place where it is poſitive to that where negative.

miles in thickneſs, as in the atmoſphere, may be quite luminous, though the light from it be diminiſhed by the diſtance from the eye. The light was fainter in every degree of the rarefaction, when there was moiſture in the tube, from my having put a little bit of wet leather in the rec^r (which however was dried in the exhauſtion;) and this inclines me to think, that it is *air* burnt and exploded in its paſſage which makes the electric matter viſible; and that were there no air, if it could paſs at all, it would not be luminous: for though we were to ſuppoſe, that the electric matter would be rendered luminous by mere watery vapour without any air; yet I imagine the extreme cold, in very elevated regions of the atmoſphere, would freeze this vapour, as it does near the earth, and condenſe it into icicles, deſtroying its elaſticity; ſo that it could not aſcend, by its expanſive force, beyond that height, in which there would ſtill be air, though of great tenuity: if theſe things be ſo, the Aurora Borealis is confined within our atmoſphere.

N. B. The pear-gage with its metal caſe and wire, being within the rec^r prevented me from knowing what would be the appearance of the electric matter in paſſing through it.

I had not an electrical machine mounted; ſo could not in theſe experiments try the effect of continual electrification, and it

it has not been in my power to repeat them: if it had I would not take the liberty to offer them to the public ſo imperfect: they are preſented as hints to direct the enquiries of others, who are ſo circumſtanced as to be able to proſecute them, and alſo as ſuggeſting perhaps the beſt teſt of the pneumatic engine's exhauſting power.